A CRITICAL STUDY OF VARIOUS ASPECTS OF CONVENTIONAL AND MODERN TUNNELING TECHNIQUE WITH REFERENCE TO HIMALAYAS

A DISSERTATION

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WATER RESOURCES DEVELOPMENT

By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled "A CRITICAL STUDY OF VARIOUS ASPECTS OF CONVENTIONAL AND MODERN TUNNELING TECHNIQUE WITH REFERENCE TO HIMALAYAS " in partial fulfillment of the requirement for the award of the degree Master of Technology in Water Resources Development submitted in the Water Resources Development Training Centre, Indian Institute of Technology - Roorkee is an authentic record of my own work carried out under guidance's and supervision of Prof. Gopal Chauhan and Dr.B.N.Asthana. This is to further certify that I have worked for a period from July to December'2002 for the preparation of this dissertation.

The matter embodied in this dissertation has not been submitted by me for the award of any other Degree.

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SYNOPSIS

"A CRITICAL STUDY OF VARIOUS ASPECTS OF CONVENTIONAL AND MODERN TUNNELING TECHNIQUE WITH REFERENCE TO HIMALAYAS"

Construction of tunnels or tunneling works for underground construction such as Hydro Electric power station, water conveyance, subway, etc. are required for water resources development projects. These need accelerated pace of construction.

Tunneling works and cavern excavation generally use drilling and blasting methods. *Conventional methods* of tunneling generally comprise of *drilling and blasting, rock bolting (anchoring), wire meshing, shotcrete, grouting and lining.* Conventional methods of tunneling are slow and need long time to complete the work.

The modern tunneling usually deploys equipment such as *Tunnel Boring Machine* (*TBM*), so that time-period for construction can be faster than conventional method. The modern tunneling technique is being widely used in U.S.A and Europe in all type of geological formation and for all diameters (2 to 12 meter) of tunnels. They use the tunnel-boring machine. There are however advantages and disadvantages of using conventional and modern techniques, depending on condition of rock, time-period available and budget of the project.

For the design method of construction tunnel, has to be considered depending on *type of rock, geological condition, size and shape of tunnel.* In this way an economical estimate of cost may be developed.

The TBM has several *advantages* over the Conventional (Drill and Blast) method, which are enumerated below:

- *Very fast progress,*
- *Minimum risk and hazards,*
- *Smooth tunnel finish, no over-cut or undercut,*
- *No shattering effects on rock and thus requires minimum supports.*

The *disadvantages* are:

- *Capital cost and running cost are very high,*
- *Uneconomical in shorter length of tunnel,*
- *Different design and type of cutter head roller are required for different type of rock.*
- *Very heavy inventory and sophisticated maintenance facilities are needed at site,*
- *Very elaborate and accurate investigation is required to decide most suitable TBM.*

In this dissertation different aspects about conventional and modern tunneling technique, which are available for tunneling works, have been critically examined and compared.

To illustrate the above aspect, data from *Nathpa Jhakri Hydro Electric Project* representative of geology and geological nvestigation of Himalayas is used.

Each step sequence of construction method has been analyzed, so that a conclusion for economical tunneling process may be arrived at.

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Chapter 1

INTRODUCTION

1.1. GENERAL.

Tunneling is generally a major component of any hydropower project as far as time and cost is concerned. Before one can plan the construction of tunnel or estimate its cost, it is necessary to have knowledge of the different equipment and construction methods that can be used. Tunneling activities divided into three groups:

- *Tunnel haulage equipment;*
- *Equipment unique to excavating the heading in the conventional manner viz: drills, jumbos, and mucking machines;*
- *Facilities necessary to service the first two groups.*

The choice of equipment and methods for conventional tunnel excavation is influenced by the following variables: *structural characteristics of the ground, length of the tunnel, diameter of the tunnel, grade in the tunnel and the applicable laws covering the use of diesel engines in underground construction activities.* Descriptions of tunneling equipment are given in broad terms, but because of continued equipment development, any description of equipment rapidly becomes outdated. A tunnel engineer should contact equipment manufacturers and inspect tunnels that are under construction to secure more equipment details and to keep up with improvement and developments in this field (1)-p.18

1.2. TUNNEL CONSTRUCTION.

Tunnel construction *is the continuous excavation of one hole through the crust of the earth.* It presents special problem in that there is only one surface where work can be done, the end of tunnel called the *face*. All effort is concentrated on advancing this face as fast as possible. The men at the face are called the *heading crew*. This crew's responsibility is to excavate the face day after day until the tunnel is holed through. All other men and appurtenances in the tunnel, service this crew to facilitate their progress. They supply the heading with *fresh air, compressed air, water, black powder, drills, mucking equipment, hauling equipment, and supports,* as needed. After being excavated, tunnels may or may not be lined with concrete.

The construction of intake and outlet works, shaft, adits, ventilation structures, underground powerhouse, and other underground structures utilize similar procedures. (1)-p.2

1.3. HISTORY OF TUNNEL CONSTRUCTION.

The beginning of man's efforts to go underground by means of subterranean excavation are lost in the haze of antiquity, but there is abundant archaeological evidence that in Europe Stone Age man sank shaft and drove tunnels to recover flint for the fabrication of sharp-edge implements such as knives, axes, arrowhead, and scrapers. Later, as primitive people acquired an elementary knowledge of metallurgy, possibly by for the first time in central Asia, underground mining became necessary to supply the increasing demand for metals and alloys in technology and culturally advancing civilizations. Very early underground excavation for metal bearing ores have been identified in Caucasian, between the Black and Caspian Seas, and date back to approximately 3500 BC. From this center and others of unknown location and through ever-expanding communication and trade, knowledge of mining and metallurgical technique spread in all direction through out the civilized world.

Many tunnels were built in ancient times by the Babylonians, by the Aztecs and Incas in the search for the precious metals, and by the people of India, Persia, and Egypt. The Romans, superb planners and engineers, built many tunnels, some connecting with still-standing aqueduct and others as integral parts of highway systems or military operations.

Stone Age man used very primitive tools in underground excavation. Particularly useful to him were picks made of the deer antlers, flint axes, and hammers, and wedges made of bone and wood. The discovery of smelting and production of metals and alloys, first bronze, and later iron and steel, provided materials for increasingly efficient rock excavation. However, even with metal tools and until the first underground use of explosives in the seventeenth and, especially in the eighteenth centuries, mining of hard rock was a difficult challenge that could be overcome only by fire-setting. For hundred and perhaps thousands of year underground workings in hard rocks, especially those containing few fractures and fissures, were advanced by building fire against rock face to cause expansion and spalling. In some operation, dowsing it with water accelerated spalling of the heated rock. The fractured rock was then separated from the working face with picks, gads and wedges.

Hand-in-hand with the increasing use of explosive, first "*black powder*" and later *nitro-glycerin* and *dynamite*, steel tempering techniques were perfected and permitted efficient and economical hand-drilling of hole for explosives in the hardest of rocks. Near the middle of the nineteenth century steam-powered piston drills, and later, pneumatic percussion drills, powered by compressed air, made their appearance; and at about the same time, but with less than notable success, several tunneling machines (*moles*) were invented and given field tests. Without exception, all of the early tunneling machines were dismal failures, but the pneumatic rock drills proved their worth and have played a major role in the development of the modern technology of rock excavation. Again, after more than a century, tunneling machines are being given increasing attention, and because of many notable successes in rapid and economical driving of tunnels, must be considered as offering a reasonable and competitive alternative to driving tunnels by conventional methods employing pneumatic drills and explosives. (10)-p.1

1.4 *TUNNELING METHODS.*

For tunnel in rock until recently were driven exclusively by so-called *conventional* or *classical methods*, that is, by drilling and blasting. As required, supports were installed to contain bad section of ground and to provide safety for the workers. Special operation included sealing-off of water flows by grouting and installation of tunnel linings appropriate to the designed function of the tunnel.

In the 1950's, *James S. Robbins and Associates* developed a successful rock-tunneling machine that was used in Canada, and a new era of mechanization of tunneling was born. Since then, numerous companies in the USA and abroad have developed tunneling machines, popularity called " ***moles*** ".

To select between conventional and mole method, more detailed information about geological condition is required.

1.4.1. Conventional Tunneling Method.

Conventional tunneling methods, also called "*classical*" methods, are cyclic operations involving, in sequence, *drilling, blasting, mucking and installation of required supports*. The cycle is interrupted for special operation such as grouting, or spilling through very difficult ground.

In large tunnels, much of the activity at the tunnel heading is cantered around a jumbo, a platform or a tier of platforms mounted on wheels or skids. The jumbo is used during drilling operations, loading of drill hole with explosives, and provides working access to the arch and walls of the tunnel as supports are installed.

In most modern operations, tunnels in competent rock generally are driven "*full-face*", even when the tunnels have large cross-sections, as in highway tunnels. However, especially in the late nineteenth and early twentieth centuries, large tunnels were driven by a series of small tunnel excavations, called "*drifts*", in various portions of the larger tunnel heading.

Multiple-stage advance of tunnel headings is today used in very difficult or incompetent rock. It is well known that caving, running, or heavy ground is much more easily managed and contained in small openings than in large openings, and excavation of one or several small heavily-supported tunnels sometimes provides the only feasible means of penetrating sections of highly-incompetent rock. In some situations stabilization before advancing the tunnel heading requires extensive grouting, or drifts which are filled with concrete around and outside of the planned tunnel opening.

1.4.2 Tunneling Machines.

Tunneling machine has been used to excavate tunnels with diameters of about 2 m (6 ft) to more than 11 m (36 ft). Rate of excavation of over 120 m (400 ft) per day have been recorded in *soft ground.* Excavation at the rate of about 30 m (100 ft) per day in moderately *hard limestone and sandstones* is routine. Rate of progress, other factors being equal, is proportional to the strength, toughness, and hardness of the rocks intersected in the tunnel, and it is common practice to correlate progress with the compressive strengths of rocks. Advance in technology now make mole excavation possible in rock that have compressive strengths of 1460 kg/cm^2 (20,000 psi) and grater, although most successful operations in past have been in rocks with compressive strengths of 1095 kg/cm^2 (15,000 psi) or less.

Tunneling machines generally are site specific for a particular project, and the design includes consideration of the kinds of geologic conditions that are anticipated. Important structural elements of a typical mole include a rotating cutter head, and provisions for controlling forward thrust and alignment. A canopy or shield system provides protection from falling rocks and enables safe installation of tunnel supports near the face of the tunnel. Cuttings from the face are transported to the rear of the machine by a variety of devices. Forward advance is controlled by a laser beam, which provides precise alignment and grade for the steering the machine. (10)-p.207

1.5 CONVENTIONAL VERSUS MOLE TUNNELING.

The impetus in modern tunneling is toward increasing use of tunneling machines. However, before a tunneling machine is specified for particular operation, a careful comparison should be made between the advantages of driving the tunnel with a machine as compared with tunnel excavation methods, that is, by drilling and blasting. In some situation, consideration should be given to employing both methods, taking advantage of especially applicable techniques of each method. Any decision that is made about the method of tunneling ordinarily is based on engineering and geological factors, which determined the costs of tunneling. However, special circumstance may dictate the use of a tunneling machine, as, for example, in a densely populated or industrialized are where blasting in a shallow tunnel might cause extensive damage to surface structures and underground utilities.

Advantages to be gained by using tunneling machines, assuming that geological condition are not adverse, are follows:

1. A smooth circular cross-section is obtained. Such a section has maximum stability and creates the most favorable distribution of stresses in rocks around the tunnel. Less support is required in drilled and blasted tunnels.
2. There is not blast damage and rock around the tunnel is left essentially intact.
3. Over break associated with conventional tunneling is absent or minimal, and the volumes of concrete or rockcrete used in lining us much less than is a typical drilled and blasted tunnel.
4. In suitable rock, the rate of progress of the tunneling operations is much greater than in conventional tunneling operations.

5. Blast damage to buildings or underground facilities in industrial and residential areas is eliminated.
6. Less manpower is required in a mole operation than in cyclic, conventional tunneling.

Factors limiting the use of tunneling machine include the following:

1. The initial cost of the tunneling machine is high, much more than equipment required for conventional tunneling. Accordingly, tunneling machines generally are not practicable for shot tunnels or tunnels of very large diameter and intermediate length unless such tunnels are located in areas of population or industrial concentrations where conventional mining might lead to damage suits.
2. Large and complex ventilation systems may be required to reduce dust and heat and to provide suitable working condition near the tunnel heading.
3. Control of alignment and grade may be difficult in soft section of rock.
4. Working room at the tunnel heading is very limited as compared with the available room in conventional tunneling methods.
5. Rapid adjustments of techniques and equipment to changing rock conditions cannot be made with the same ease as in conventional methods.
6. Tunneling machines generally are designed for the specific requirement of a particular project.
7. Costs of tunneling with moles in very hard rock are high and may not be competitive with costs of conventional tunneling.
8. The mobility of tunneling machines is much less than equipment used in conventional tunneling.
9. Tunneling machine yield poor performances where very hard rock alternate with soft rocks or where extensive zones of highly altered and fractured rocks containing swelling, squeezing or running ground are encountered.

Analysis of the above statements is essential in each case. In any proposed tunneling operation, at the planning and design stage, consideration should be given to the relative advantage and disadvantages of mole excavation versus conventional excavation. It is essential that the decision as to which method be employed should be made *only after completion* of a thorough, professional investigation of the geological conditions along the tunnel alignment.

1.6. OBJECTIVE OF STUDY

The objective of this study is to describe the studies that are necessary to be made to plan the construction and to estimate the cost of tunneling construction project. It also aims to plan the tunnel construction activities including the selection of tunneling equipment.

1.7. ORGANISATION OF STUDY.

The study is presented in following chapters:

Chapter 1. It gives introduction to tunneling.

Chapter 2. It describes the geology and geological investigation with reference to *Nathpa-Jhakri project.*

Chapter 3. It covers study of conventional tunneling methods.

Chapter 4. Study of modern tunneling equipments and case study for Tunnel Boring Machine on Himalayas is presented in this chapter.

Chapter 5. Comparison of conventional and modern tunneling method for *Nathpa-Jhakri* tunnel has been done in this chapter.

Chapter 6. It describes of problems the conventional and modern tunneling method for Himalayas area.

Chapter 7. The conclusions of the present study are presented in this last chapter.

Chapter 2

GEOLOGY AND GEOLOGICAL INVESTIGATION WITH REFERENCE TO NATHPA-JHAKRI PROJECT

2.1. GENERAL

Explorations for tunnels are made to help determine the feasibility, safety, design and economics of a project. More specially, some of the purposes of explorations are:

- *To define the physical characteristics of general material through which a tunnel is to be driven;*
- *To provide specific rock or soil design parameters;*
- *To help define the limit of certainty for the project, and to alert the engineer to possible conditions that may arise during construction so that he may prepare contingency plans;*
- *To remove uncertainties of material conditions for the bidder;*
- *To establish design conditions so that a "change in design condition" can be fairly determined during construction;*
- *To provide experience of working with the material, which, in turn, will improve the quality of field decisions made during construction.* (13)-p.11

2.1.1. Planning

Before a tunnel can be planned in outline and designed in detail much information on the physical aspects of the project must be sought in addition to, and having a direct bearing on, economic studies. The need for detailed and extensive investigation is probably greater than for most other types of construction. Tunneling is costly, but it may become costlier if false economy to save on the information required for making the best choice of line, level and methods, is resorted to.

The topography of the area concerned must be studied to the fullest practicable extent, together with the history of any relevant ground disturbance, as must its geology and geo-technology.

Investigations for a tunnel should be a continuing activity throughout its planning, design and construction. As each item of information is utilized, new and more detailed problems appear and further investigations become necessary. (16)-p.77

The general planning of possible routes and levels based on the broad topography is followed by more detailed examination of possible alternatives to the point where the most favorable alignment can be selected. Even at quite a late stage a substantial change of level or line may be found advantageous, where more competent, or ground more suited to particular equipment may be found. In any case, further and fuller information on the ground structure through which the tunnel is to be driven will be a continuing requirement, and it is likely that there will be a need for probing ahead through the tunnel face where there may be any doubts about variations in the ground.

2.1.2. Topography

The first approach is the study of existing maps to largest available scale, including contours or other information on levels. A site inspection will be advisable at an early stage and as often as possible thereafter in order to appreciate the significance of the features mapped and the general characteristics of the area.

The work may be in open country, mountainous or alluvial, or in a city center with large and important building, a suburban area or an industrial area. The survey may be required to include accurate location of existing tunnels whether to avoid interference or to joint up.

Aerial photographic survey can be most valuable both in speed and in accuracy of recording detail. It is well known that in the countryside it may sometimes reveal the unexpected presence of ancient working.

The framework of the survey should be used as a basic of a full and accurate record of the construction including more particularly such ultimately concealed parts of the structures as temporary shaft and adits, or any areas of extensive over break in tunnel or temporary excavations refilled.

2.1.3. Geology

Geological survey and geo-technical studies of surrounding ground are fundamental to planning, design and construction. Stratigraphy, petrology and tectonics are all relevant but much finer detail of structures and variation is necessary for tunneling than for broader geological purposes. Soil mechanics and rock mechanics studies follow the basic geology to assist in predicting the mechanical behavior of the ground during excavation and its interaction with supports, temporary and permanent.

Initially, geological information is available from published maps and memoirs, which are often supported in detail by unpublished records accessible to those interested. The alluvial deposits, and types of rock occurring in the area and their interrelationship will be shown on maps but precise interface position and changes in texture and strength are likely to be of great significance in tunneling and must then be the subject of fuller exploration.

Any records of previous boring may be of great value. Inspection of exposures in quarries, pits, shafts and mines is usually worthwhile including those in cliffs and streambeds and any excavations. Records of earlier tunnels should be sought and of well and deep foundations.

The major items of geological and geo-technical information required include:

1. *Geological description with details of lithology and variability.*
2. *Location and orientation of discontinuities and planes of weakness relative to tunnel excavation-bedding planes, joints, faults, shear zones.*
3. *In situ stresses,*
4. *Geo-mechanical properties.*
5. *Ground water.* (16)-p.81

2.2. TYPES OF ROCK

Considering the origin of rocks, a genetic distinction may be made among:

- *Igneous rock*, formed by cooling and solidification of fluid, molten magmas;
- *Sedimentary rock*, deposited from fluid suspensions or solutions to build up stratified accumulations, and
- *Metamorphic rock*, which in response to elevated temperature and / or pressures in the earth's crust, were transformed by changes in fabric and mineralogy into rocks differing more or less from the original rock.

2.2.1 Igneous Rocks

One class of igneous rocks, described as extrusive, emerged from the interior of the earth in molten state through vents or fissures in the uppermost part of the earth's crust, which is cool and solid. Upon emerging, the molten rock flowed over the landscape, forming streams or lakes of lava. Owing to relatively rapid cooling, the resulting rock is fine-grained. Two common representatives of this group are *rhyolite* and *basalt.*

Rhyolite is a light-colored rock, chiefly composed of quartz and feldspar. Its unit weight is about 2560 kg/m^3 (165 lbs./ft^3). Basalt is a dark-colored rock composed chiefly of feldspar and pyroxenes. Its unit weight may be as high as 2880 kg/m^3 (180 lbs./ft^3). Engineers commonly call dark-colored fine-grained igneous rocks, such as basalt or andesite, trap rock.

In some localities the molten rock never reached the surface of the earth; it remained within the earth's crust in chambers, which are produced either by doming the solid rock above it or by stopping and by melting the solid rock. In these chambers, the molten rock cooled and crystallized very slowly. Because of slow cooling, the constituents occur in the form of crystalline grains large enough to be seen with the unaided eye.

Rocks, which originated in this manner, are known as *intrusive* rocks. *Granite* is a common representative of this group. Its chemical and mineralogical composition is similar to that of *rhyolite,* from which its coarser grain distinguishes it. *Diorite gabbro* is another member of group; its composition corresponds approximately to that of basalt.

2.2.2 *Sedimentary Rocks.*

Sedimentary rock may be divided into several groups. The most important groups comprised the *clastic* sedimentary rocks. The term clastic is applied to rocks, which are composed of fragment produced by the disintegration of previously existing rocks of any kind. The clastic sedimentary rocks include *conglomerate, sandstone, and shale.* Another group of sedimentary rocks include most *limestones* and *dolomites,* which consist largely of the hard parts of such marine organisms as clams and corals.

2.2.2.1 Origin and deposit of Sediments

The raw material of the clastic sedimentary rock consists of rock waste. The debris produced by rock weathering is picked up by brooks, transported in suspension by rivers or shore currents and deposited at the end of the line of transportation, in a lakes on flood plain, or in the proximity of the sea shore. The coarse grained sediments are known as *sand* and *gravel* and the fine grained ones as *silt* and *clay.* By the deposition of cementing material in their interstices, sand and gravel are gradually transformed into sandstone and conglomerate.

2.2.3 *Metamorphic Rocks*

Metamorphic rocks represent *the result of the process of re-crystallization, which took place at high temperature and high pressure.* The properties of the product depend on the nature of the rock subject to metamorphosis and, to considerable extent, on the deformation associated with the process.

2.2.3.1 *Changes produced by high temperature and pressure*

When a rock is subjected for a long time to high temperature combined with high pressure, its porosity decreased, its strength increases and the unit weight of the solid material increases due to the loss of the chemically bound water. *Limestone* is transformed into *marble* and *sandstone* into *quartzite.* Under the influence of the moderate temperature and pressure, *shale's* are transformed into *fissile slates* and *schist's*, which are known as *low-grade metamorphic rocks.* With increasing temperature and pressure, they are metamorphic to very hard and dense *gneiss,* classed as *high-grade metamorphic rocks.* Since the metamorphic rocks derived from silt and clay are among the most obnoxious troublemakers in tunnel construction, they deserve the tunnel builder's special attention. (19)-p.22

2.3. *FIELD DATA FOR NATHPA-JHAKRI TUNNEL.* (18)

The *Nathpa-Jhakri* Hydro Electric Project envisages hydro power generation of 1500 MW (6 x 250 MW) utilizing a drop of nearly 488 meter (gross) along the *Sutlej* river in a reach of nearly 30 km between *Nathpa* village where the diversion dam would be located, and the *Jhakri* village near which an underground power house is proposed. The geological details and other data are given in ***Fig.2.1*** at the end of this chapter.

2.3.1 *General Geology of the Project Area.*

Nathpa-Jhakri area is underlain by ***quartzite, gneiss's- schist and gneiss's***, which are intruded by amphibolite, granite and pegmatite. The gneiss's are sub-divisible into massive gneiss, flaggy or banded gneiss and augen gneiss. The foliation strikes *East-West* and dips by 30° toward North. Fold axes trend *Northwest-Southeast* or *East-West.* Eight sets of joints are present, among them four sets are more prominent.

The *s-schist* of the *gneiss* is more foliated than gneiss's. The foliation usually strikes N 70° W – S 70° E to 70° E - S 70° W with dips averaging 30° towards North. The foliation however strikes Northwest-Southeast between *Nigulsari* and *Sholding Khads* with dips of about 40° on either side. On the eastern side of *Sholding Khad* the foliation strikes almost North south dipping by an average of 25° toward west, then from 324.5 km on Head Race Tunnel. Road it again assumes its usual East-West strike trend with dips of 25° towards North.

The *gneiss's* are more jointed than *gneissose-schist.* The following sets of joints are present.

1. Strike North-South to N 20°E – S 20°W with dips 70° on either side to sub-vertical. Then joint set is generally closed, but occasionally open and clay filled. The frequency of occurrence is from one joint per meter to very close spacing causing sheeting.
2. Strike N 15°W – S 15°E to N 5°E – S 5°W with dips of 35° toward west. The highest frequency of occurrence is *five* joints per meter.
3. Strike NE-SW with dips of 75° on either side to sub-vertical. The joint is open occasionally with frequency of *two* joints per meter.
4. Strike N 25°E – S 25°W with 45° dip towards S 65°E. frequency is *three* joints per meter.

5. Strike Northwest-Southeast with dips sub-vertical. This joint set is either absent at places, but wherever present the frequency of occurrence is as high as *nine* joints per meter. It has also causes sheeting of rock.
6. Strike N 65°W – S 65°E dips 30° to 60° towards S 25°W.
7. Strike N 80°W – S 80°E to N 70°E – S 70°W with sub-vertical dips. This the second most important joint set in some localities, and
8. Strike East-West with dips of about 30° toward South.

   The country rocks are well folded. Most of the major fold axes run Northwest-Southeast and East-West. Some of the major folds are listed below:

   a. *Daj Khad* anticline and syncline, axis N-S.
   b. *Manglad Khad* open syncline-down-warping axis N 30°W – S 30°E.
   c. *Bathara* anticline and syncline-axis N 70°W – N 70°E.

2.3.2. *Tentative Geological Forecast along HRT alignment.*

Forecasts of geological conditions anticipated along the tunnel alignment are as follows:

At the tunnel, grade *gneissose-schist* (poor to satisfactory) is expected for 11.79 km (41.46%), *augen-gneiss* (satisfactory) for 5.95 km (20.92%), *massive gneiss* (good) for 2.83 km (9.95%) km (20.92%), *massive amphibolites* (good) for 2.25 km (7.92%), *granite* (good) for 0.09 km (0.32%) and *schistose patches* in amphibolite (very good) for a cumulative length of 1.31 km (4.6%). The rock type for a distance of 1.5 km (5.26%) is not known in view of the section lying deep in the core area of a fold.

Rock shattered at the axial region of larger folds has been recorded from:

9.96 km – 10.14 km	*(0.18 km)*
11.68 km – 12.44 km	*(0.76 km)*
15.10 km – 15.42 km	*(0.32 km)*
19.44 km – 20.11 km	*(0.17 km)*
20.90 km – 21.20 km	*(0.30 km)*
21.72 km – 21.79 km	*(0.07 km)*
27.19 km – 27.26 km	*(0.07 km)*

The cumulative width of shattered rock zone is 1.87 km. In addition width of shattered rock zones are interpreted between 1.14-km – 1.15 km (10 m), 18.21 – 18.23 km (20 m), 18.25 – 18.28 km (390 m). The cumulative width is 0.76 km.

Fault have further been inferred to intersect the head race tunnel at 6.62 km, 16.18 km and 20.31 km. Assuming a ten meter thick sheared or fractured zone for each fault, the cumulative width is about 0.03 km.

Besides a faulted and sheared zone along the *Sholding Khad* exist from 6.76 km to 6.82 km (0.06 km). About 70% of the alignment is sub-parallel to the foliation plane of country rocks therefore; the magnitudes of rock pressures may be quite high. Beside hovering or sliding pressure may also be high at the inlet and outlet portals due to some reason. Genuine mountain pressure (primary) are expected to be severe wherever the tunnel grade is located under high rock cover, but the magnitude of the some is likely to be dependent on geological structure and tectonic disturbance. In the present case these pressure may be higher whenever the tunnel is located along foliation strike or at the axial region syncline.

The country rock is *gneissose-schist* with the foliation striking N 50°W - S 50°E, dip 30° towards N 40°E and N 60°E – S 60°W, dip 25° toward N 30°E on the right and left sides of the Khad respectively. An anticline with axial trend North-South is located almost along the *Khad*. The axial portion of this fold is sheared with a width of about 100-m at this place. This shear zone comprises blocky and fractured rock with kaolin and sericitised matrix and is since situated along a *Nala*, it is likely to be fully water charged. The most prominent joint set strike N 10°E – S 10° W dipping 50° toward S 80°E.

(*Table: 2-1*) ***Tentative Geological Forecast along HRT alignment.*** (23)

Rock Quality	***Rock Type/ Structural Condition***	***Actual Length***	***Percentage***
1. Good	a. *Gneiss* b. *Massive amphibolites* c. *Granite*	2.83 2.25 0.09	9.95 % 7.92 % 0.32 %
2. Satisfactory	*Augen Gneiss*	5.95	20.92 %
3. Satisfactory to poor	*Gneissose-schist*	11.79	41.46 %
4. Poor	*Shattered rock zone*	1.87	6.57 %
5. Very poor	a. *Schistose Patches In amphibolites* b. *Fault & shear zone*	1.31 0.85	4.60 % 3.00 %
6.Unexplored area	-	1.50	5.26 %

2.3.3. *Drifts.*

1. *Rai-Khad (Unoo-Nala) drift No.D5:*

This drift has been drive in southwestern direction, subsequently veering toward northwest, with portal at the left scarp face of *Rai-Khad (Unoo-Nala)*, about 100 meter upstream of road bridge. The objective is to ascertain the tunneling properties, of *amphibolites* and *quartz-schist,* which overlies the former. It is, further decided to ascertain the nature of contact between the two rocks mentioned above the contact appears to be disturbed.

The drift portal is located in amphibolites with a thin band of chlorite-schist and it runs through amphibolites interspersed with many bands of *biotite-schist* up to RD 80 meter. However, the *biotite-schist* bands occurring between RD 12.5 m and 13.5m, 78.0 m and 79.5 m and that beyond RD 79.5 m are thicker. There is repetition of these *biotite-schist* bands due to minor folding together with the enclosing amphibolites around RD 40 m. in addition to the above feature thick *biotite-schist* bands containing irregular block of massive amphibolites are also present from RD 54.5 m to 68 m and 74 m to 77 m.

The bedrock foliation strikes N 40°E – S 40°W at the portal but swings gradually to North-South then N 60°W – S 60°E and ultimately reverts to strike trend of N 60°E – S 60°W at RD 67m. The dips of foliation are toward west to Northwest and are of the order of 20° in most of the cases. Various fold axes with a plunge of about 20° toward N 80° W intersect the drift. Three sets of joints are also seen their attitudes are as follows:

i). Joint set trending in N 70°E – S 70°W direction and dipping 70 toward N 20°W is the most prominent. These joints are generally tight.

ii). Joints trending in N 35°E - 335°W direction and dipping 60° toward S 55°E are open and through these water seeps into the drift.

iii). The set striking N 25°W – S 25°E and dipping vertically is also a closed set and is almost insignificant in this drift. This drift has to continue to the proposed depth of 100 m.

2. *Nigulsari Drift.*

The objective of this drift has been to asses the tunneling conditions in the gneiss and intrusive granite, presence or absence of geothermal conditions in the granite portion and the residual tectonic stresses at the two rock contact mentioned above. The portal of the drift is located in *augen-gneiss* about 20 meters below the new H.T. Road near km stone No.318. The drift had progressed 56 m by 31-8-1978, in an S 40°E direction up to 19 m in S 42°E direction from 19 m to 45 m, then finally in a S 40°E direction in the last stretch.

The drift runs, for its entire excavated length of 56 meters, in coarse-grained gneiss. The foliation of bedrock strikes N30°E–S30°W to northeast southwest with dips ranging between 45° and 55° toward northwest. A quartz-vein is present at RD 15 m and several pegmatite-veins, with thickness ranging between 0.2 m and 4.5 m are interspersed although. Joint sets striking at N 70°E – S 70°W and dipping at 70° toward S 20°E are spaced at 0.1 m interval and are prominent between RD 0 m and 15 m. Due to above joints set and the steep valley slope, glide-cracks with opening towards *River Satluj,* have been recorded up to 35 m length. At places, infiltrated clays have filled up these glide-cracks. Major glide cracks are present at RD 4.5 m, 11.0 m, 24.0 m, 24.50m, 30 m, and 35-m a major slip-plane, trending N 20°W – S 20°E and dipping at 50° toward S 70°W, has been recorded on the left wall between RD 18 m and 28 m. Moist conditions, with minor drips are seen up to 53 m. the drift has to be extended further to 100-m depth as proposed.

2.3.4. Drill Holes.

1. *Raikhad (Left Bank) Drill Hole.*

This has been drilled at the intersection of H.R.T alignment and *Raikhad* on the left bank. A summarized lithological log of the drill hole is as under: *(table: 2.2)*

Depth range in meters		**Nature of strata**
From	**to**	
G.L	42.67m	*Overburden, comprising boulders gneissose schist, amphibolites in clayed to sandy matrix.*
42.67 m	*59.43 m*	*Quartz Sericite-Schist*
59.43 m	*152.86 m*	*Amphibolites containing (inter calations of chlonite and or biotite schist.*

Large amount of shallow subsurface water is found. Foliation dip ranging from 0° to 38°.

2. *Daj Khad Borehole.*

This bore hole (El. + 1518.8 m) has been drilled in *Daj Khad* near the proposed tunnel alignment. The summarized log is given below:

(Table: 2.3)

Depth below G.L in (m)		**Nature of strata**
From	**to**	
0.00	6.55	*Overburden*
6.55	33.99	*Shattered Gneissose – Schist*
45.72	47.55	*Gneissose Schist*
45.72	47.55	*Shear Zone*
47.55	87.32	*Gneissose Schist with Quartz Vein*
87.32	88.85	*Shear Zone*
88.85	110.15	*Gneissose – Schist*

Discharge = 7.5 liter/min.

3. *Kandlu-Khad drill hole No.4 (31°33'55"; 77°50'29"; 53E/14).* This drill hole is located at the junction of *Kandlu-Khad* and New H.T. Road, and has been drilled down to 104.24 m. the brief litho-log is as below: *(table: 2.4)*

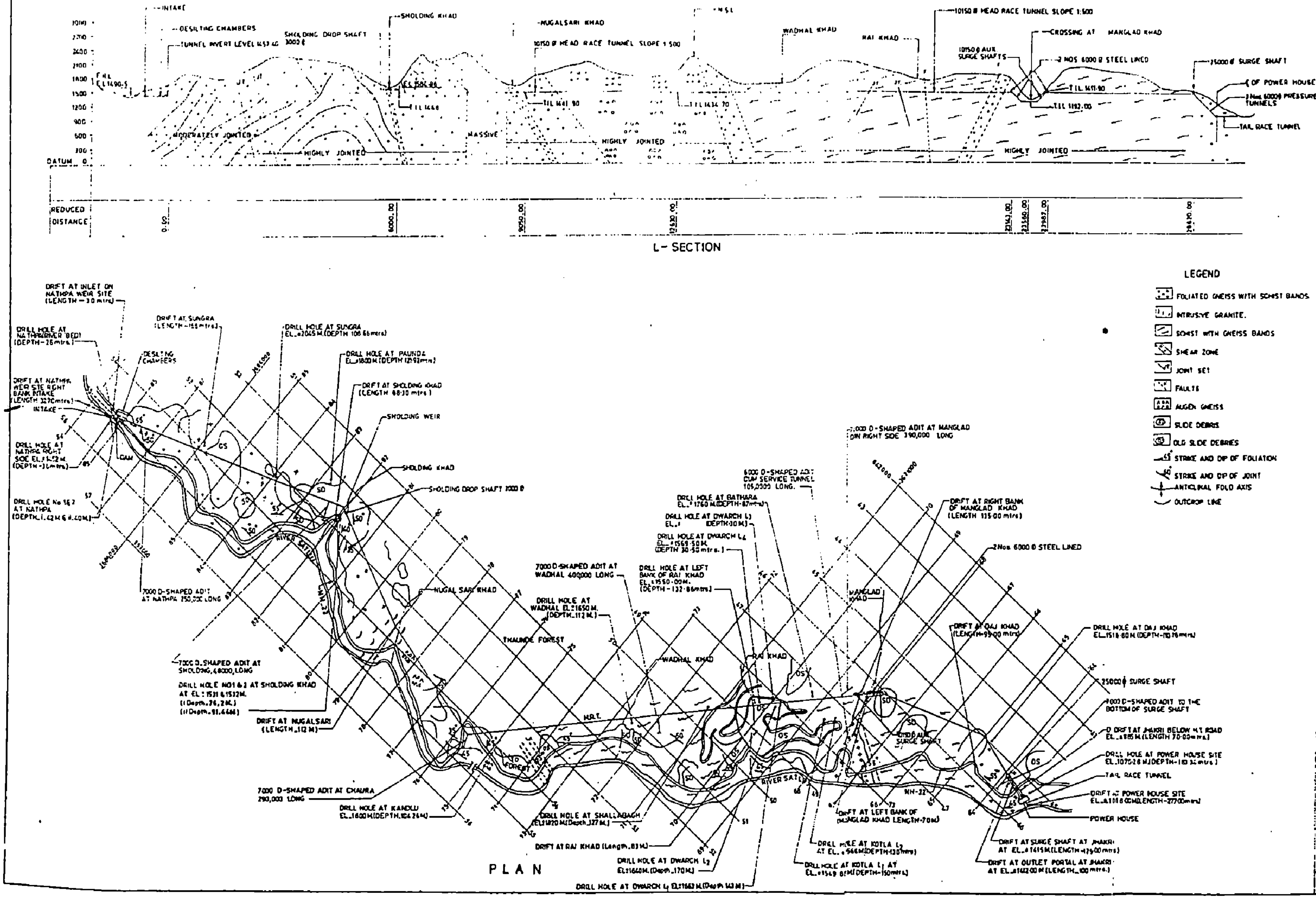
Depth below G.L in (m)		**Nature of strata**
From	**to**	
G.L	*15.8*	*Overburden comprising soil and boulder.*
15.90	*39.56*	*Gneissose – Schist*
39.56	*47.56*	*Thin intercalation of gneissose-schist and augen gneiss.*
47.55	*67.67*	*Gneiss with thin gneissose-schist bands.*
67.67	*73.67*	*Gneissose Schist with thin augen-gneiss bands.*
73.76	*104.24*	*Augen-gneiss, with thin gneissose-schist bands in the upper portion and two amphibolite bands in the lower portion.*

2.3.5. Predicted Rock Pressures

The expected rock pressures as given below table, are for general guidance and may not hold good in faults and shear zones. A shear zone having a length up to tunnel diameter may have no effect on the general pattern of rock loading but in wider shear zone the rock loads shall be higher.

(Table: 2.5)

Rock Type	**RQD**	**Predicted Rock Pressure in** (Kg/cm²)
1. Top weathered Rock	*0*	*2.50*
2. Open jointed schist	*15*	*2.0 – 5.0*
3. Biotite Sericitic Schist	*45*	*2.0 – 5.0*
4. Gneissose Schist	*20-60*	*3.0 – 5.0*
5. Quartz Sericitic Schist	*43*	*3.0 – 5.0*
6. Gneiss's	*40*	*1.0 – 5.0*
7. Amphibolite	*10-85*	*1.0 – 5.0*
8. Blocky & disjointed rock	*25*	*4.0 – 5.0*



NOTE

1. The dimensions given are in millimetres and
elevations in metres.
2. The drawing is based on contour plan supplied
field engineers.
3. The layout of the Head Race Tunnel and othe
project features is on the basis of data sup
by S E Nathpa Jhakri Construction Circle vi
letter NO NJCC_DB_8/85_4404_05 Dated 31_
4. The geological data enclosed in this set of d
is based on field reports of the Geological S
Of India for various seasons.

Fig. 2.1

Scale :- 1:30000

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Chapter 3

CONVENTIONAL TUNNELING

3.1. GENERAL.

The conventional tunnelling techniques *centre round a drill, blast and muck cycle, repeated one after another until the tunnel is completely drilled.* With the conventional methods, a tunnel of any shape or size can be constructed. The efficiency of tunnelling, however, depends upon *the diameter of the tunnel, type of ground encountered, drilling rates and patterns, the blasting pattern, the muck handling and removal system.*

A few of many possible methods for penetrating highly incompetent rock are indicated in illustration, such as:

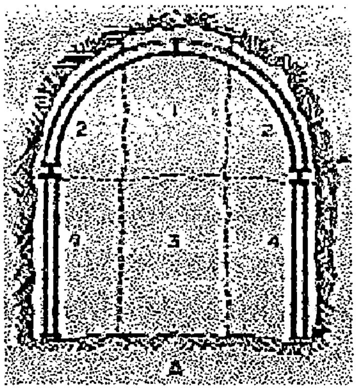


Fig.3.1

A top drift is excavated (1) and with appropriate installation of temporary supports is expanded laterally (2), to enable placement of arch ribs or wall plates. This operation is followed by driving a bottom drifts (3), which is widened (4) to install wall ribs below the arch ribs.

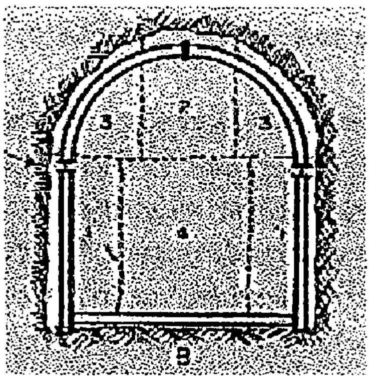


Fig.3.2

The wall ribs are placed within side drifts (1) and capped with wall plates. Leaving a central core (4) excavations (2, 3) are made to install the arch ribs. Finally, the core is removed, and an invert strut is bolted or welded to the wall ribs.

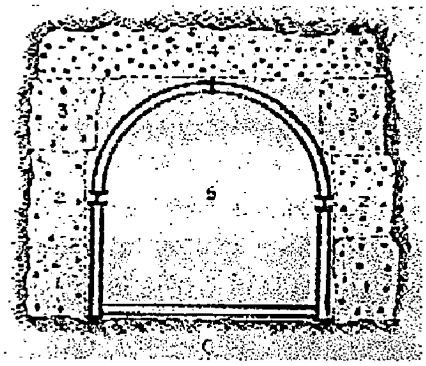


Fig.3.3

In extremely incompetent rock, it may be required to drive a succession of drifts (1,2,3,4) and fill them with concrete, before excavating the full cross-section of a tunnel. A capping beam (4) is constructed of reinforced concrete to support the rock load in the tunnel arch.

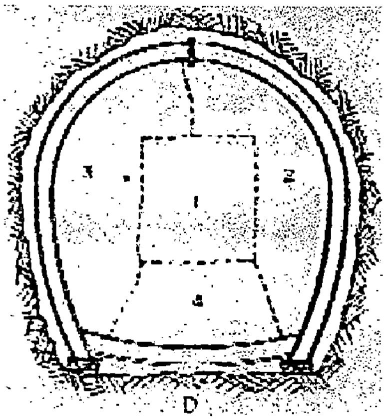


Fig.3.4

Shows a method for installing steel supports in a tunnel of intermediate size. A heavily supported central drift (1) is expanded by excavation (2,3,4) and installation of additional supports until the ribs can be placed.

The different operations of the conventional tunnelling cycle are described here in brief.

3.2. DRILLING OPERATION.

This operation has to be performed in all tunnels except where excessive running material in weak strata combined with heavy seepage flow is encountered. In such strata, alternative methods of excavation with picks etc. may be employed. The drilling of holes where drill and shoot method is employed is carried out by pneumatic rock drills, which are mounted on the drilling jumbo moving on wide spaced rails inside the tunnel. The drilling jumbo has three or four decks depending upon the diameter of the tunnel. For a 7.5m (25-ft) diameter, tunnel three decks are normally used with the lowest deck leaving an opening of 3× 3.6 m (10×12-ft) underneath for carries to pass. There are about 20 drills working at a time, provided with auto feeds. Each drill needs about 5.9m^3/min (200 ft^3/min) of air supplied at 6.33 kg/cm^2 (90 psi).

The drilling pattern is so provided that maximum fragmentation of the rock is obtained and minimum over break takes place. Pre-splitting and smooth blasting techniques may be used to minimize over break. For this periphery, holes are alternately charged and detonated with zero delay to *delink* the basic rock from the excavated section before the other holes blast.

For *full-face* excavation either *burn cut* or *wedge cut* Fig.3.1 & Fig.3.2 may be adopted. The back end of holes should be in one sloping plane to get uniform rock face after blasting.

For fast drilling, instead of the drilling jumbo with mounted rock drills, hydro boom is now being used which has got hydraulic controls to direct the rock drills in any desired direction easily and quickly.

The depth of holes will depend upon the tunnel diameter and the available facility for quick muck disposal in a relatively shot time. Usually 3 - 4.5 m (10-15 ft) pulls are taken in tunnels of diameter 7.5-10.5 m (25 to 35 ft).

3.2.1. *Drilling Pattern.*

Drilling patterns depend on the size and shape of the tunnel and quality of the rock to be excavated. Rock that is badly fractured will require a lesser number of holes than massive formations with few seams. There must not only be enough volume in drill-holes to permit placing sufficient explosive to break out the rock, but the holes must be placed sufficiently close in blocky rock so that the resulting muck will be in small enough piece to be handled efficiently by the mucking machine. The square feet of tunnel face per hole will be greater for a large tunnel than for a smaller one in the same rock and greater for softer or highly fractured rock than for hard massive formations.

The square feet of tunnel face per hole will usually vary between the limits shown in Table: 3-1 or Fig.3.5 which are in ft^2 unit and have not been change to SI units for the scale of retaining originality.

Table: 3-1 *Blast hole requirement.* (13)-p.142

Area of tunnel face (feet²)	*Tunnel Face per Hole (feet²)*	
	Soft or Highly Fractured	*Hard or massive*
100	4.5	2.25
200	5.3	3.25
250	6.0	4.00
400	6.4	4.50
500	7.0	4.90

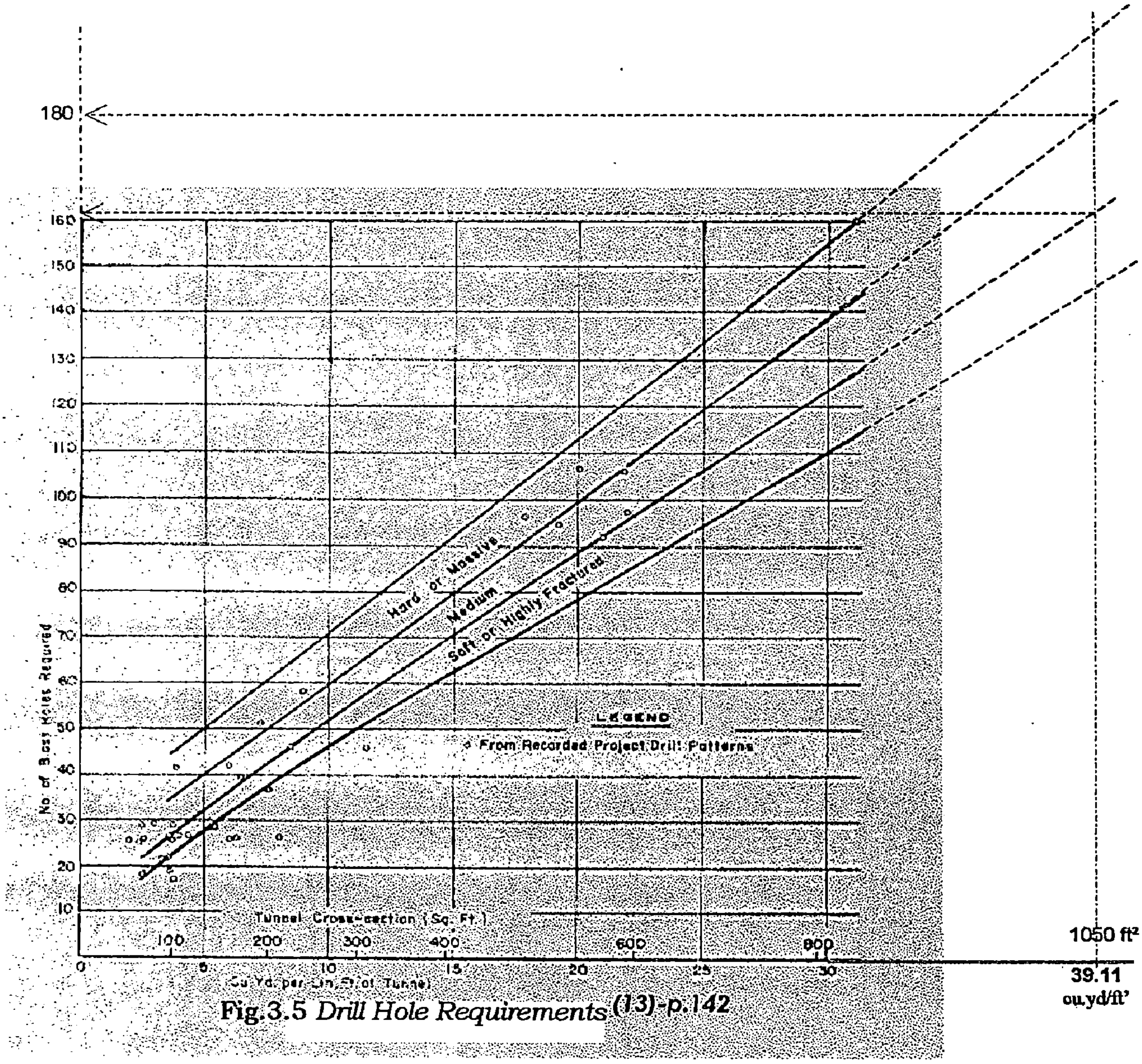


Fig.3.5 *Drill Hole Requirements* (13)-p.142

Positioning the cut indicates the drilling pattern design and the contour holes. Secondly, the production holes are positioned adjacent to the contour and thereafter the position of the lifter holes is fixed. Finally, position of the production hole is fixed. When fixing the production holes adjacent to the cut sufficient room for the cut breakage should be allowed.

The offset is between 0.2 – 0.4 m. the burden in the transition zone between the contour holes and the production holes must be reduced by an amount equal to the offset.

For the practical reasons, to ease the drilling and loading operations, it is normal to position the cut 1.0 – 1.5 m up from the floor and alternately on either side of the centreline to avoid collating a hole into a socket.

It is important to facilitate effective drilling when positioning the cut and designing the drilling pattern. An even distribution of the drilling work between the drills is necessary for making the drilling time as short as possible. The loading of the cut is most effectively done from the floor.

Blasting as close as possible to the pre-fixed is ever increasing requirement-likewise with respect to the quality of the remaining rock. Accurate drilling of the contour holes is important in this respect. Too much offset of the contour holes will give a pronounced '*sawtooth*' shaped profile and extensive damage to the remaining rock in the transition zone between the blasts.

The holes adjacent to the contour holes shall be given an offset angle equal to that of the contour holes. Poorly performed contour blasting will given an unnecessary amount of back breakage, increased clean up and stabilisation work, and poor quality of the final product. The result will be loss of pressure in water tunnels and increased maintenance for rail and road tunnels. The risk of failing rock is dangerous and also a traffic hazard.

The lifter holes should be given the same offset angle as that of the contour holes.

$$\text{Number of lifter holes} = \frac{\text{Tunnel width} + 2 \times (\text{Offset of contour holes} + 1)}{\text{Distance between holes}}$$

Suggested values for burden and distance between holes based on practical experience and rock of medium blastability are as follows:

Borehole diameter: 34 – 38 mm.

Contour diameter:	Burden 0.6 – 0.8 mm	distance between holes 0.5-0.8 m.
Next row:	Burden 0.9 m	distance between holes 0.8 m.
Lifter holes:	Burden 0.8 m	distance between holes 0.7 m.

Borehole diameter: 45 mm.

Contour diameter:	Burden 0.8 – 1.0 mm	distance between holes 0.7-1.0 m.
Next row:	Burden 1.0 m	distance between holes 1.1 m.
Lifter holes:	Burden 1.0 m	distance between holes 1.0 m.

3.2.2. Type of Cut.

The number, arrangement and depth of holes and the charge weight and firing sequence are decided to suit the size, shape, and particular conditions of the tunnel, the available equipment and the blasting characteristics of the rock.

The basic drill pattern consists of:

a. *Fan cut,*
b. *Wedge cut,*
c. *Parallel cut, large diameter,*

1. *Fan cut.*

The principle of the fan cut is breakage/back ripping against the tunnel face, i.e. the only free face available. The fan cut is effective with respect to the total length of boreholes being drilled and quantity of explosive being used for each round. The cut gives a comparatively easy breakage, consuming fewer explosives. The fan cut requires a wide tunnel, which limits the advance per blast. The non-symmetric drilling makes the cut less effective when applying modern drilling equipment. The fan cut is still being used in shot tunnels and with plain drilling equipment.

2. *Wedge cut.*

In the wedge cut, the holes are drilled at an angle to the face in a symmetrical formation. The angle of the wedge must not be too narrow. The burden is increased with decreasing angle. The symmetric pattern distributes the drilling work evenly between the drills. The increased burden requires more explosives and more drilling work as compared with the fan cut. The advance depends upon the tunnel width and the wedge cut is consequently most suited in wider tunnels.

A wedge cut blast throws the broken rock further out of the tunnel face as compared with other types cuts. This makes it more cumbersome to scale the roof and the face from a position on top of the muck pile and it increases mucking time. The greater throw of fired rock is also more likely to cause damage to ventilation ducting close to the face.

3. *Parallel cut.*

The parallel cut consists of one or larger diameter unloaded boreholes. All holes are drilled at a right angle to the face and parallel to the tunnel direction. The breakage is against the opening or void formed by these unloaded holes of diameter 76-150 mm.

This opening in gradually opened up by successive detonation of the adjacent loaded holes and the pulverized rock is blown out of the cut. The parallel cut requires a weak load along its entire length. Packaged explosives of composition giving gas energy with low gas temperatures are used.

Modern electric / hydraulic drilling equipment will drill up to 152 mm in diameter. The large diameter cut holes are initially drilled as pilot holes, and of the same diameter as the production holes.

Several large diameters cut holes will help to secure good breakage along the entire length of the advance.

The length of the advance is in principle independent of the cross section of the tunnel.

Parallel cuts give in general better breakage and fragmentation of the rock with less throw-out and spreading as compared with the V cuts. This in turn reduce loading time and also makes it more convenient to scale the roof, walls and face of loose rock from a position on top of the pile.

Bedding and blasting of the rock together with borehole diameter and length of advance are important factors in the planning process. The advantages of the parallel cut, large diameter, are:

- *Well suited for drilling with modern drilling equipment,*
- *Well suited for rounds of long length,*
- *The length of the advance is in principle independent of the cross section or width of the tunnel,*
- *Good breakage,*
- *Moderate throw-out and spreading of the pile. Reduced loading time and scaling of roof, walls and face from a position on top of the pile,*
- *Good fragmentation.*

It is a precondition of the parallel cut, large diameter, that the rock blasted into the empty boreholes has sufficient room for complete blowouts. Based on experience, this requires very accurate drilling and carefully selected delay times and sequence of detonation for loaded holes adjacent to the cut.

When designing the cut, we may use curve Fig.3.6 as a starting point to find the required large diameter hole area for the cut. The curve is based on experience.

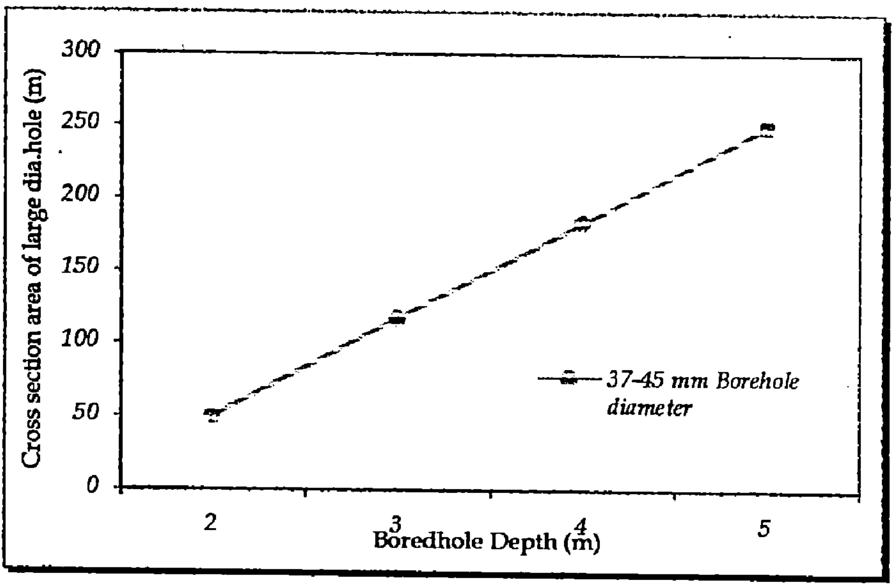
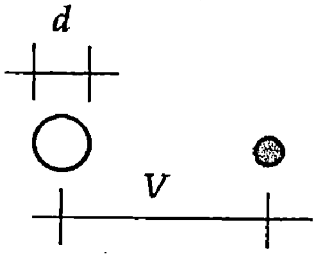


Fig.3.6 Required area of empty diameter holes for parallel cut as a function of borehole depth, blastability and borehole diameter.

The distance (burden V) between the large diameter unloaded cut holes and the adjacent loaded holes is given by the formula:

Burden $V = 1.5 - 2.0 \times d$



● Loaded hole: Diameter 37 – 45 mm.

○ Large diameter hole: Diameter 76 – 102 – 127 mm
other dimension in meters.

The burden V for the other holes of the cut is governed by the width B of the established opening. Based on experience with rock of medium blastability:

Burden $V = 0.7 \times B$

Fig.3.7 Gives suggested burden as a function of the established opening.

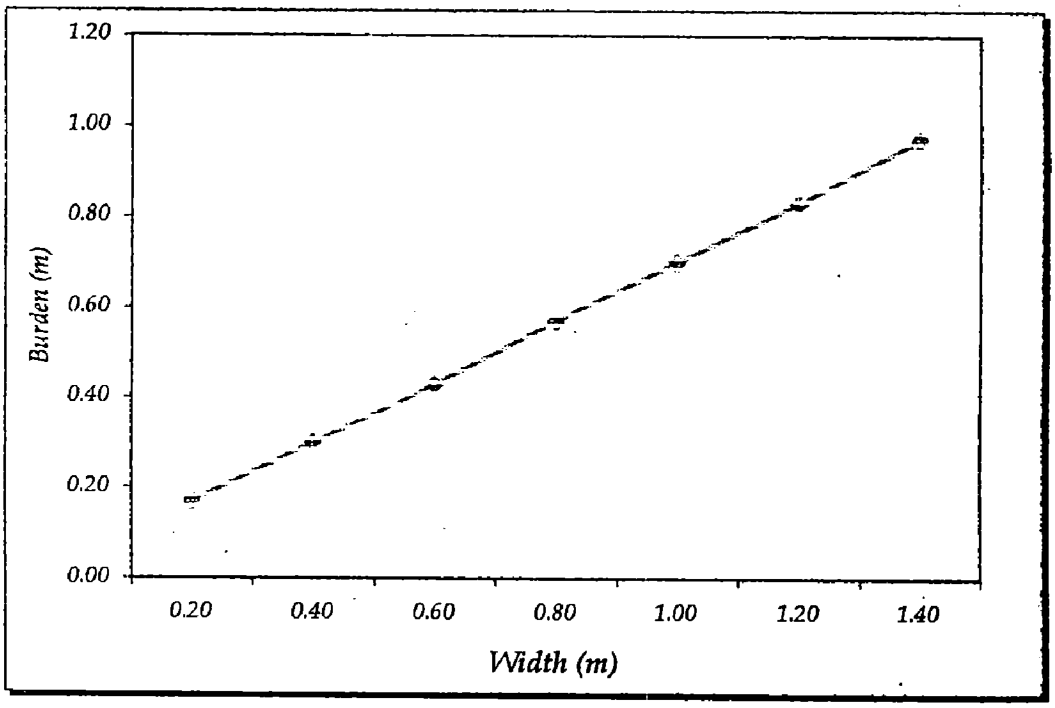


Fig.3.7 Suggested burden as a function of blasted opening.
Rock of medium blastability.

The required amount of drilling is specified as the number of boreholes per round for the given cross-section of the tunnel. The more important factors governing the extent of required drilling include:

- *Blastability of the rock,*
- *Cross section of the tunnel,*
- *Borehole depth,*
- *Borehole diameter,*
- *Type of cut to be used.*

For rail and road tunnel and rock caverns specifications are often given for the contour blasting in terms of boreholes distances, type and quantity of explosives being used.

The required number of boreholes, exclusive of the large diameter unloaded holes of the parallel cut, is given in Fig.3.8 for 34 mm and 45mm diameter holes.

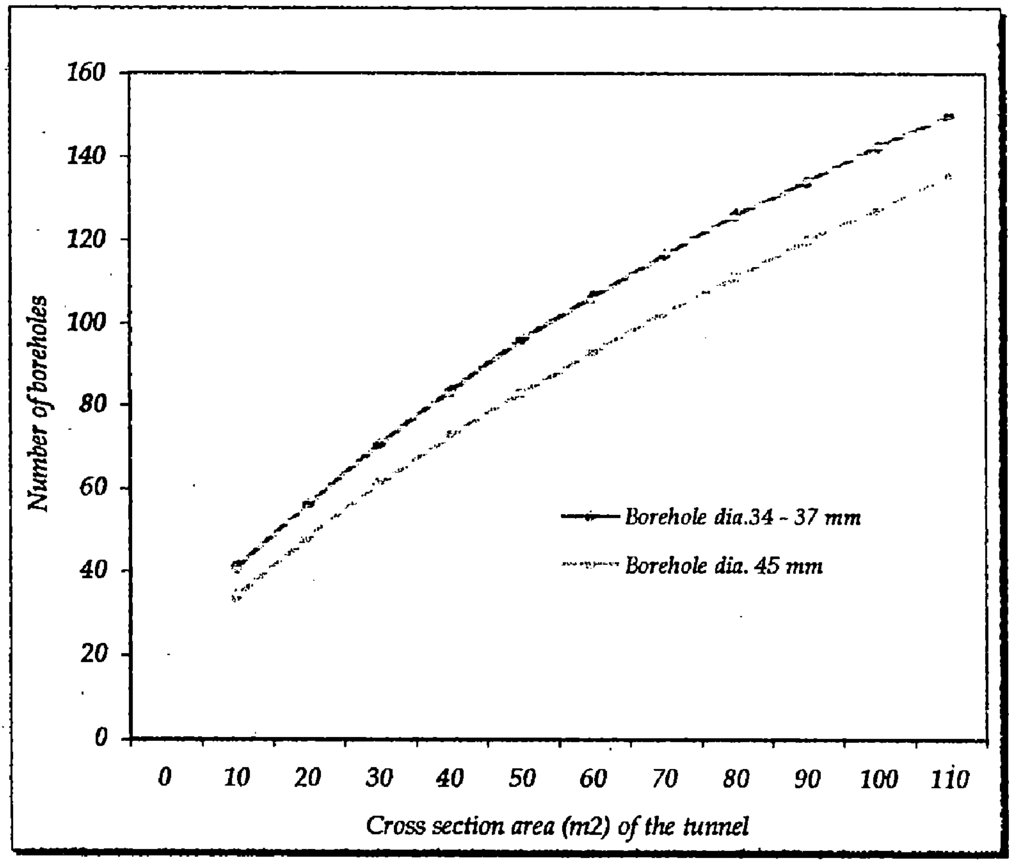
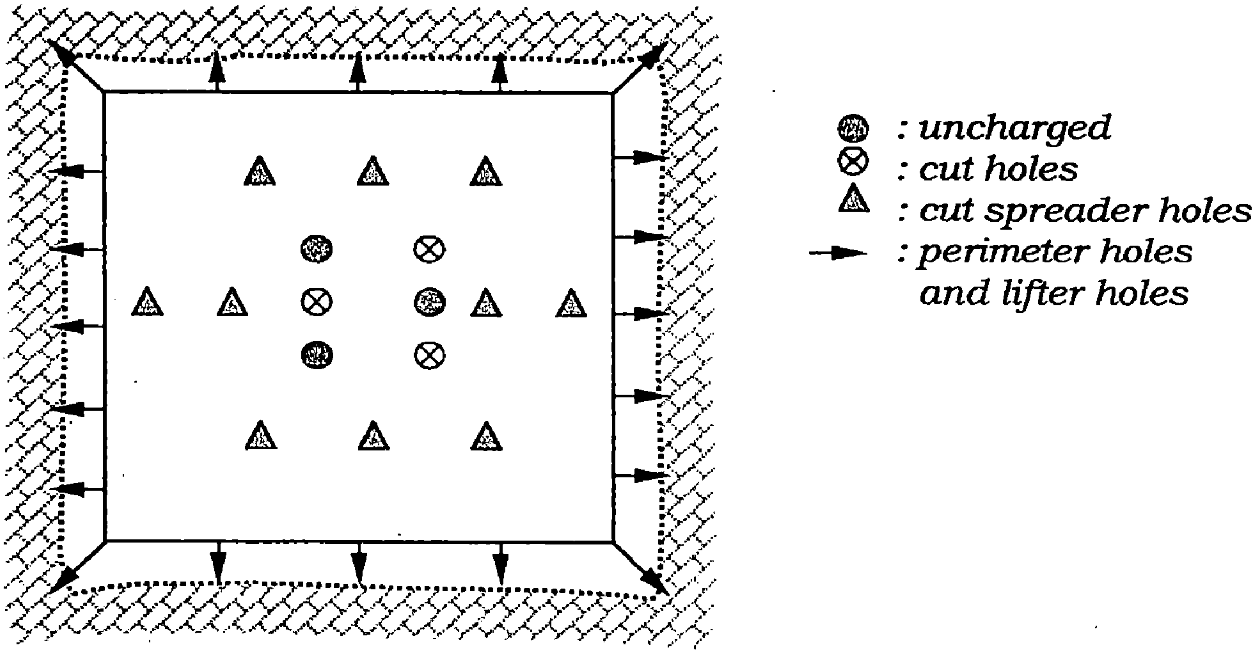
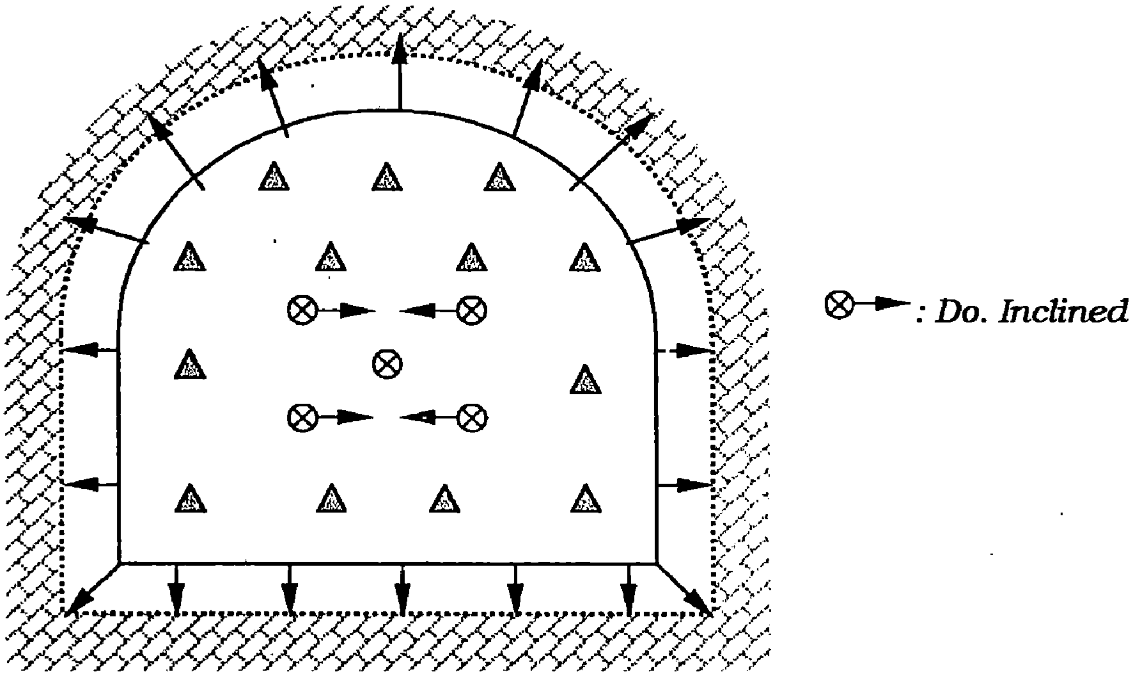


Fig.3.8 Required number of boreholes exclusive of the large diameter holes in the parallel cut-rock of medium blastability – borehole depth 4.5 – 5.0 m [illegible]



- *Fig.3.9 Box Type Burn Cut*



- *Fig.3.10 Wedge Cut*

3.3. BLASTING OPERATION.

There are two types of explosives (*called powder, in tunnel parlance*) in general use for tunnel excavation. They are *nitro-glycerine dynamites* and *ammonium nitrates*. Dynamites are mixtures of nitro-glycerine and other substances. They are rated in strength according to the percentage of nitro-glycerine. They are manufactured in ratings of 15 to 90 %. The energy produced per kilogram of explosive is not in proportion to the percent of nitro-glycerine, as other ingredients add to the energy produced: 60% dynamite is only 1½ times as strong as 20% dynamite. The blast effect is determined not only by strength, but also by density and velocity. Density can be expressed by the number of cartridges of a particular size contained in a 22.5 kg (50-lb) case. There may be only one-third as many of the denser cartridges as the least dense. In hard rock, the denser dynamites are required to break the rock, so these are generally used in tunnelling. Cartridges are manufactured in various sizes. The most generally used size in tunnelling is 3 × 20 cm (1¼ × 8 inches). Gelatine dynamites are dense and most water-resistant, and up to a 60% rating they have better fume characteristics. Thus, they are preferred for tunnelling (40% and 60% gelatines are best adapted to tunnel work).

Ammonium nitrate, in the form of fertilizer pills, when mixed with form 1 to 12 % carbon black, powdered coal or fuel oil (5 to 7% by weight of fuel oil gives the best performance), has become a favourite explosive in tunnel work because of its lower cost. It requires a dynamite cartridge in each hole primed with an electric blasting cap to cause it to explode. Ammonium nitrate is not water-resistant so it can only be used in relatively dry tunnel or when encased in plastic bags.

The amount of powder required to break rock out from a tunnel heading is much greater than in an open cut because of its confined location. Smaller tunnels require more explosives per unit of excavation than do larger tunnels. Harder massive formations require more powder than softer formations. Powder consumption can vary from over 5.31 kg/m³ (9 lb/yard³) in a massive hard granite formation in 3.35 m (11-feet diameter tunnel to less than 1.18 kg/ m³ (2 lb/yard³) in softer or less massive formation and large-diameter tunnel. (10: 3.156)

There are two main categories of authorised explosive: *'permitted explosive'* approved for used in *gassy condition*, more particularly where the presence of methane is possible, as in coal mines; and those for general use in *non-gassy conditions*. They are further classified as *gelatinous*, *semi-gelatinous* and *non gelatinous*, and slurries explosives. For tunnelling, gelatinous and semi-gelatinous explosives are almost always employed, having high water resistance and high density (*in the sense of concentration of explosive energy*). They have to be used in long small diameter holes and must therefore be sufficiently sensitive for the detonation to travel without failing the whole length of the long narrow column. The choice of the particular grade of explosive will depend in part on the hardness of the rock and on the wetness at the face.

The handling, storage and use of explosive in a tunnel require particular care. Every stage of the process from delivery at site to ultimate use should be most strictly regular and should at all times be under the control of named responsible persons, who will ensure compliance with statutory requirements, safety codes, and other rules and procedures special to the project. When a tunnel is advancing steadily a very regular routine will usually be established for each shift and it becomes very important that the hand-over from one shift to the next is property organised and that there is no laxity in observing safety rules.

After having drilled the holes on the tunnel face, these are charged with the explosive. Three types of these explosives as generally manufactured by I.C.I (India) are:

a). *Gelatinous with 80 % dynamite,*
b). *Gelatinous with 60 % of dynamite,*
c). *Gelatinous with 40 % of dynamite.*

In case of very hard rock, the 80 % of *gelatines* should be used in the central holes and 60 % of *gelatines* in the rest of the holes except 2 rows of outer periphery where 40 % *gelatines* may be employed. In very hard rocks, 40 % of *gelatines* may have to be avoided and for very soft rocks 80 %, *gelatines* may not be used. In fact, the results of blasting are a good guide to this division.

3.4. MUCKING OPERATION.

Excavation material in a tunnel is known as *muck* and the *loading* of it into vehicles for transportation is known as *mucking.*

After a round has been blasted, some of the rock that has been broken loose will hang in a precarious position, endangering the safety of the crew. On returning to the face after a blast, the walls and roof should be washed down to permit careful inspection of the rock surface. The first operation is to scale down any loose rock in the tunnel roof or side that might cause injury to personnel. This usually takes only a few minutes and is accomplished while equipment and services are being brought forward and prepared for mucking.

3.4.1 Mechanical Loaders.

This involves the loading of the excavated muck at the driving face into a haulage system constituting either of mine cars hauled by *locos* or *pneumatic tired* carriers-normally employed in large diameter tunnels. The efficiency of the whole tunnelling cycle depends upon the efficiency of this system as this operation takes, the maximum time. For loading, a *Conway mucker* of 46 m^3/hr (60-cyds/hour) capacities or an *Eimco shovel* of 0.765–1.15m^3 (1-1.5-cyd) bucket capacity is used depending upon size of the tunnel. The Conway mucker output is quite large and hence it is useful in big tunnels only. The belt conveyor system would be the most efficient for muck disposal but is prohibitive in cost.

The tunnels driven in comparatively weaker strata require the rock supporting which may be done by *rock bolting,* by *shotcreting,* by *providing ribs and wood lagging,* and also by *initial concreting behind these ribs.* The extent of these supports depends upon the rock conditions inside the tunnel. For drainage, suitable holes are provided and water pumped out from sumps located along the tunnel length. The alignment of tunnel is done regularly after every blast with survey instrument or a laser beam.

The tunnels with diameter of 10m (33 ft) and above should be driven using *two-stage* excavation. The first stage up to the diameter level is driven as described earlier all tunnelling problems being confined to this portion only. The lower half is started as an *open cut* only when the upper half has been completed. This method effects saving of both time and money in tunnel excavation,

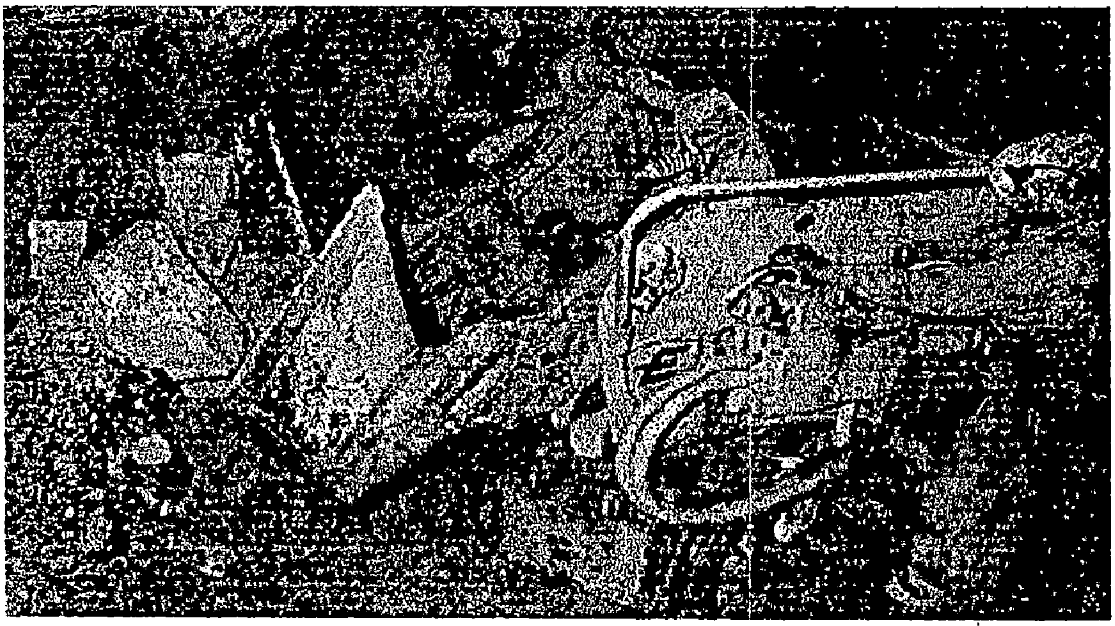


Fig. 3.11 Eimco rocker shovel (79)-p.155

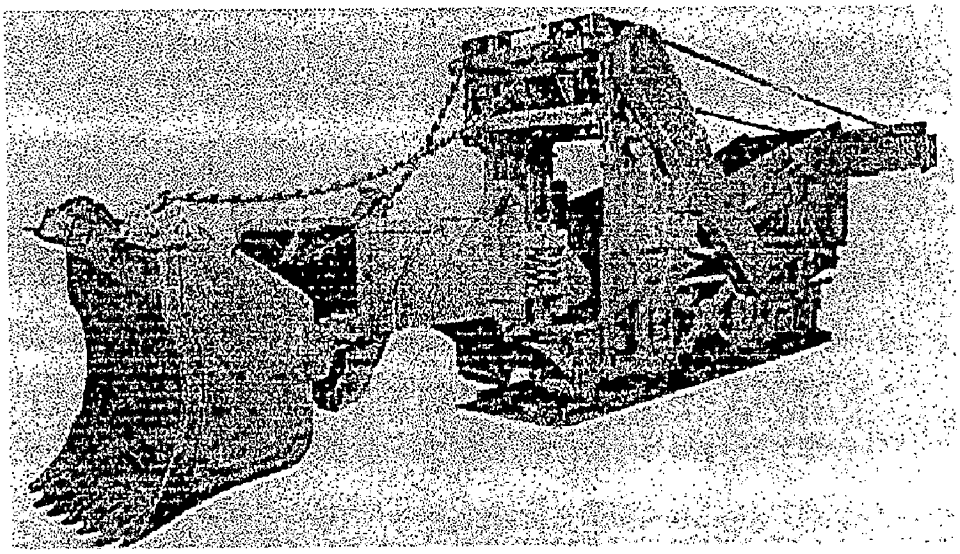


Fig. 3.12 Convey mucker

3.5. TUNNEL SUPPORTS.

The history of the development of various techniques for installing supports in the tunnels, especially in incompetent rocks, is a fascinating tribute to the ingenuity of man in overcoming seemingly impossible obstacles.

Through the ages, timber and masonry supports in various configurations served their purpose well, but today steel, concrete, and mortar are the materials most used in construction of tunnels with uses projected over long periods. Timber is still used extensively in mining operations, where permanent support is not necessary, and in tunneling operations constructed with steel, concrete, and mortar as temporary supports. Timber has an unquestioned use because of the ease with which timber members are dimensioned and shaped to meet special purposes.

Materials commonly used for supporting of tunnels (and other kinds of underground opening) excavated in rock fall into several categories, as follows:

1. *Steel ribs,* also called *bents,* which give rigid to semi rigid support. The ribs are made from *I-beam* or *H-beam* structural steel bent to conform to the requirement of a particular tunnel cross-section.

2. *Timber* members are used in variety of ways to provide propping or temporary support, and to provide a protective covering above the steel ribs. Where possible, timber members are removed before placing permanent concrete lining.
3. *Steel liner plates.* These are placed outside of the ribs to prevent movement of rock materials into the tunnel opening.
4. *Rock bolts.* These are bolts with expansible anchors, which are set in drilled holes in the arch or walls of a tunnel to improve rock competency.
5. *Wire-mesh* or perforated *steel mats.* Heavy steel wire mesh and steel mats are used to contain fragmented rock in the tunnel arch.
6. Miscellaneous steel members. Steel members of a variety of shapes and dimensions are used for special purposes. Included are tie bolts, steel lagging, and units such as rails, rods, or channel-iron used in spalling through caving ground.
7. *Gunite* is a form of plaster (*mortar*) consisting of *fine-sand, cement* and *water* which is shot at the arch or walls of a tunnel by air pressure to provide *waterproofing* and, in some instances, structural support. Commonly rock-bolted or pinned wire mesh is installed before applying the gunite.
8. *Shotcrete* is a quick-setting thick plaster or mortar shot at rock exposures. A mixture of *cement* and *aggregate* up to three-quarters of an inch are applied pneumatically and are mixed with a rapid hardening agent at the nozzle of a spraying device. The shotcrete leaves the nozzle at the velocity of about *150 m/sec* (500 ft/sec) and establishes in 5 cm (*two-inch) layers* until a desired thickness is attained.

Grout is a mixture of *cement* and *water forced* into rock around the tunnel periphery to add strength to fractured rock and intercept water flows.

3.5.1. Concrete Method

Shotcrete has been defined as concrete or mortar conveyed through a hose and pneumatically projected at high velocity onto a surface.

The use of *shotcrete* sprayed on concrete is an effective method to stabilize badly cracked structure and weak zones. The method is primarily used as a temporary measure to allow permanent stabilization to be performed later in the schedule. *Shotcrete* will gradually be dissolved in zone with running water, especially in salty water. Consequently, *shotcrete* is not a permanent measure.

The alternative will in most cases be a cast concrete lining. Running water, especially seawater, breaks down all concrete. Water must be drained off before concrete is sprayed on. The same applies to cast concrete linings.

Shotcrete is an effective way of stabilizing zones containing clay deposits. The pouring of a complete concrete lining can be the only solution under extreme conditions, often in combination with other means of stabilizing the rock such as rock bolting and shotcrete lining may cause the water pressure to build to an unacceptable level. In such cases, the water must be piped out through pipes running through the scaffolding. The piping is fitted with valves, which can be closed for subsequent grouting work.

Two processes of placing *shotcrete* exist, the *wet-mix* and *dry-mix* processes. (13)-p.337

3.5.1.1. Wet-mix Process.

The wet-mix process consists of mixing measured quantities of *aggregate, cement* and *water*, and introducing the resulting mix into a vessel for discharge pneumatically or mechanically through a hose to final delivery from a nozzle. It has the advantage of rigidly controlling the *water/cement* (w/c) ratio of the product. Existing equipment can handle maximum aggregate size to minus ¾ inch. Further, successful methods have been devised to introduce quick acting accelerators to the delivery hose. Pumping the very low slump concrete is commonly a problem, so a slightly higher than desirable water content is used. By use of accelerators, such concrete can be made to adhere overhead, but ultimate strength usually suffers. However the method has been found convenient for use with less skilled operators, in particular in the limited size access working of mines, the major percentage of which generally are dry.

3.5.1.2. *Dry-mix Process.*

Dry-mix *shotcrete* consists of a mixture of damp *aggregate* and *cement* fed into a placing machine, fed at a uniform rate into an airstreams to travel through a hose to the nozzle. The water of hydration is added at the nozzle before discharge to the surface. Water is manually controlled. Powdered accelerators are added to dry-mix as it is fed into the placer. If liquid, the accelerator is mixed with the feed water before it goes to the nozzle. The *dry-mix* process is currently the prevalent method of applying *coarse aggregate shotcrete in underground structures.*

3.6. *ROCK BOLTING OPERATION.*

During or immediately after excavation, supporting of the rock mass may be necessary to ensure the stability for safe operations.

When advancing a tunnel face by single round, half dome like double arching effect is produced as a result of loosening and expansion of overlying strata. Tension arch or loosened zone develops above and below the tunnel while the sides are in compression. The time for which this pressure arch gives reliable support (*the bridge action period*) depend upon geological conditions, the span and the diameter of the tunnel. For spans used in practice and with even weathered or strongly jointed rocks the bridge action period lasts a few hours. If no support is installed within this period, the exposed rock in the roof begins to span off involving gradual rise of the pressure arch in tendency to attain stability by decreasing the spans in conformity with its bearing capacity.

Rock bolting may be employed not as temporary support but also as permanent feature. With a suitable designed rock bolt system in a tunnel taking account of dip of strata, coefficient of friction along bedding planes and shear strength of rock, a load carrying ring is actually formed of the rock. Even if the anchor point of a bolt remains in loosened zone and the bolt is holding two or more piece within the zone their locking together may initiate arch action. A rock slab on the side of the excavation acting as a strut if bolted to rock behind would reduce effective length of the strut and chances of buckling. Although roof-bolted rock vault is employed only in arched tunnels yet roof bolting can also be advantageous in flat roofed tunnels in which case composite action of rock layers occurring by contact friction can be enhanced by roof bolts if applied in divergent planes when like bent up reinforcement bars they would effectively resist the principal tensile stresses. *(17)-p.340*

The use of rock bolting is the most effective and commonly used technique to improve stability. The technique is used in formation with crack and fissions, and in rock of *schistose* structure. Rock bolting is used in the following two ways:

1. Pre-stressed bolts, secured by expansion or with polyester. These bolts are effective immediately,
2. Grouted bolts. They required a time period for hardening and are for permanent installations.
3. Tubular bolts which are grouted when installed or later.

In badly cracked rock, straps and wire netting to secure the rock mass in between the bolts supplement the bolting.

As previously stated, almost any intact rock tunnel needs no support. It is breaking away at joints and loosening of the joint that causes rock falls. If the rock can be held together, it will then act as intact rock. To accomplish this, the use of rock bolt (*Fig.3.13*) has replaced steel rib sets in many cases where the rock is not too badly fractured and jointed. Where the rock will stand up for a sufficient length of time before requiring support, holes for rock bolts and their installation can be made from the drill jumbo while the next round is being drilled. The amount of steel and cost installed of rock bolts is much less than for steel ribs so they have largely replaced steel ribs where the rock is suitable for their installations. Rock bolt serve their purpose best when installed close behind the face. However, the optimum design must be compromised with the practical considerations of progress in the tunnel. Rock bolts are usually used in relatively good rock but can be used in some rock that would be classified as poor. They have the advantage of extending only a few inches outside of the rock, which reduces the size of the tunnel that would be necessary when using wood or steel sets for supports. In relatively good rock, they are installed where in the poorer rock; a regular pattern would be used. (13)-p.175

Fig.3.13 Rockbolting in underground powerhouse. (12)-p.175

3.7. CONSTRUCTION PROCEDURE AND TYPE OF SUPPORT. (19)-p.117

The excavating cycle a rock tunnel the usual sequence of operation is: *Drilling, Shooting (including cleaning the tunnel, loading, and firing), Ventilating, Mucking, and Erection support.*

Shortening the elapsed time required for any one or all of these operation, speeds up the rate of driving, which in turn reduces the cost by reducing the gross overhead charges.

3.7.1. *Factors determining method of attack.*

When choosing the support system the method of attack or method of excavation must be taken into consideration. The selection of the method always involves a compromise between an attempt to facilitate and accelerate the operation of mining and the necessary of supporting the rock before it starts to come down into the tunnel. Therefore the method of attack depends on the rock behaviour and on the *size* and *shape of the tunnel cross-section.*

The methods of attack most commonly used are:

- *Full Face,*
- *Heading and Bench,*
- *Top Heading,*
- *Side Drift,*
- *Multiple Drifts.*

Less frequently used are the *Top Drift*, the *Centre Drift*, the *Bottom drift* and *Bottom heading methods*, but these are usually followed by enlargement to full size in one or in *two operations*. Hence, if one of these methods is used, the most suitable type of support depends not on the initial but on the final phase of the method of the attack. This final phase can be the *full face* (*one operation*) or else the *heading and bench* or top heading method (*two operations*).

3.7.2. *Types of steel support systems.*

Rock tunnel support systems of steel are roughly of five types:

a. *Continuous Rib,*

b. *Rib and Post,*

c. *Rib and Wall Plate,*

d. *Rib, Wall Plate and post,*

e. *Full Circle Rib.*

Figure bellows illustrates these principal support systems:

3.7.2.1 Continuous Rib type

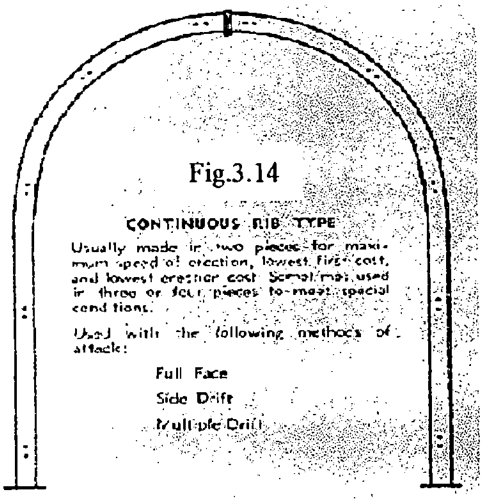


Fig.3.14

CONTINUOUS RIB TYPE

Usually made in two pieces for maximum speed of erection, lowest first cost, and lowest erection cost. Sometimes used in three or four pieces to meet special conditions.

Used with the following methods of attack:

Full Face
Side Drift
Multiple Drift

Usually made in two pieces for maximum speed of erection, lowest first cost and lowest erection cost. Sometimes used in three or four pieces to meet special conditions. Used with the following methods of attack: Full Face, Side Drift, and Multiple Drifts.

3.7.2.2. Rib and Post type

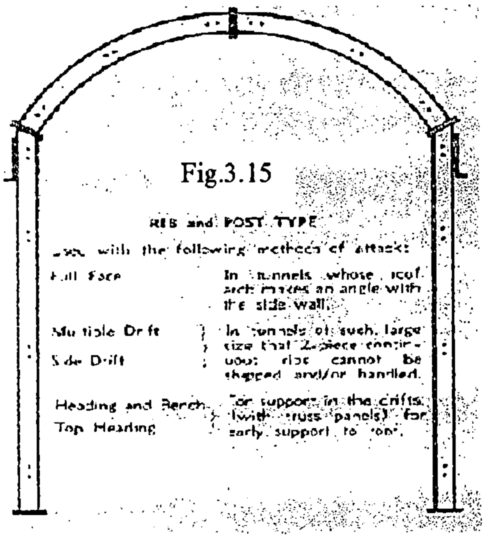


Fig.3.15

RIB and POST TYPE

Used with the following methods of attack:

Full Face	In tunnels whose roof arch makes an angle with the side wall.
Multiple Drift Side Drift	In tunnels of such large size that 2-piece continuous ribs cannot be shipped and/or handled.
Heading and Bench Top Heading	For support in the drifts (with truss panels) for early support to roof.

Used with the following methods of attack:

- *Full Face: In tunnels whose roof arch makes an angle with the sidewall,*
- *Multiple Drift and Side Drift: in tunnel of such large size that 2-piece continuous ribs cannot be shipped and/or handled.*
- *Heading and Bench and Top Heading: For support in the drifts, (with truss panels) for early support to roof.*

3.7.2.3 Rib and Wall Plate Type

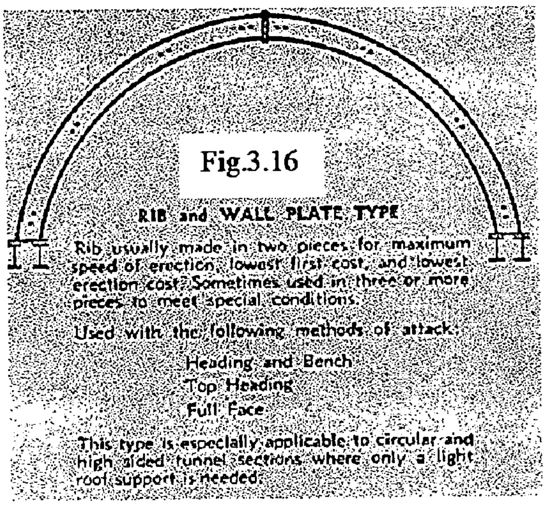


Fig.3.16

Rib usually made in two-piece for maximum speed of erection, lowest first cost, and lowest erection cost. Sometimes used in three or more piece to meet special conditions.

Used with the following methods of attack:

- *Heading and Bench,*
- *Top Heading,*
- *Full Face.*

This type is especially applicable to circular and high-sided tunnel section where only a light roof support is needed.

3.7.2.4. Rib, Wall Plate and Post Type

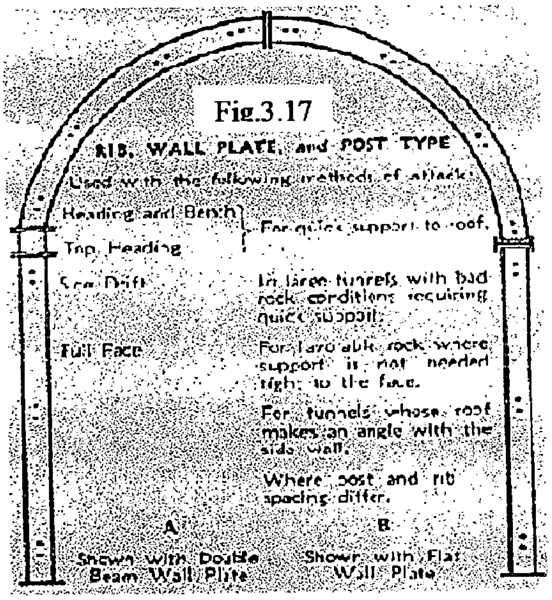


Fig.3.17

Used with the following methods of attack:

- *Heading and Bench and Top Heading: for quick support to roof.*
- *Side Drift: In large tunnels with bad rock conditions requiring quick support.*

Full Face: For favourable rock where support is not needed tight to the face. For tunnels whose roof makes an angle with the sidewall. Where post and rib spacing differ.

3.7.2.5. Full Circle Rib

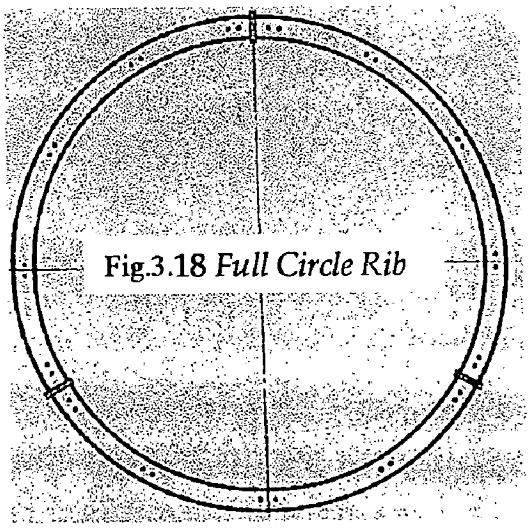


Fig.3.18 *Full Circle Rib*

Used with the following methods of attack:

- *In tunnel in squeezing, swelling and crushed rock, or any rock that imposes considerable side pressure.*
- *Also where bottom conditions make it impossible to carry roof loads on foot blocks.*
- *In earth tunnel conditions sometimes encountered in rock tunnels.*

Heading & Bench: Under earth tunnel conditions with joints at spring line.

3.8 WORKING CYCLE.

The timing of different operation for a good working cycle under Indian conditions may be as follows: *(Refer – Tunnelling Practice by Prof. S.C. Kathoch).* (15)-p.149

1. *Drilling* operation:	Time in hours:
a. Moving jumbo forward and setting	= 0.50
b. Ribbing	= 1.25
c. Drilling	= 2.50
d. Loading holes	= 1.50
e. Exhaust	= 0.40
	---------------- +
Sub-total	= 6.15

2. *Mucking* operation:	Time in hours:
a. Moving excavator to face	= 0.50
b. Scaling	= 1.50
c. Mucking and clean up	= 3.00
d. Fixing of rails for track extension	= 0.50
	-------------- +
Sub-total	= 5.50
Total time for one working cycle	= 11.65 *(Say 12 hours)*

Chapter 4

MODERN TUNNELING EQUIPMENT

4.1. GENERAL.

The modern tunneling equipment may be grouped in to three different types viz: *equipment for construction by conventional (Drill & Blast) method, Tunnel Boring Machine* (*TBM*) and *Raise-Drilling equipment.*

4.2. EQUIPMENT FOR CONVENTIONAL (DRILL & BLAST) METHOD.

Equipment for conventional method generally comprise of many types equipments such as for *Drilling, Blasting, Mucking, Scaling and Erection of supports.*

4.2.1. Drilling Equipment

The drilling equipment for medium to hard rock, the *rotary-percussive drilling* is often favored because the rig is light and good rates of penetration can be obtained.

For construction of tunnel either by heading and benching methods or by full-face attack consists of *hydraulic drill jumbo* or *rig,* which are the drilling rigs consisting of:

a. *A compressed-air or hydraulic driven rotary-percussive rock drill,*
b. *Chain feed to maintain the feed force on the bit.*
c. *Mast or leaders to support and guide the drill.*
d. *Centralizing chuck to hold the drill rod.*
e. *Telescopic boom, can be tilted and repositioned to accommodate vertical, horizontal and angle drilling.*
f. *Tracks, usually selected for surface drilling.*
g. *Compressed-air supply.*

Figures **4.1** to **4.3** show the various versions of modern drilling equipment.

Fig.4.1 *Hydraulic Drill Jumbo* (33)

Fig.4.2 *Quasar 1F compact face drilling jumbo.* (33)

The Tamrock face drilling product line covers a wide range of mining applications, starting from the compact single-boom Quasar (1.2m wide) to the Paramatic class with up to three booms and 95m² coverage area.

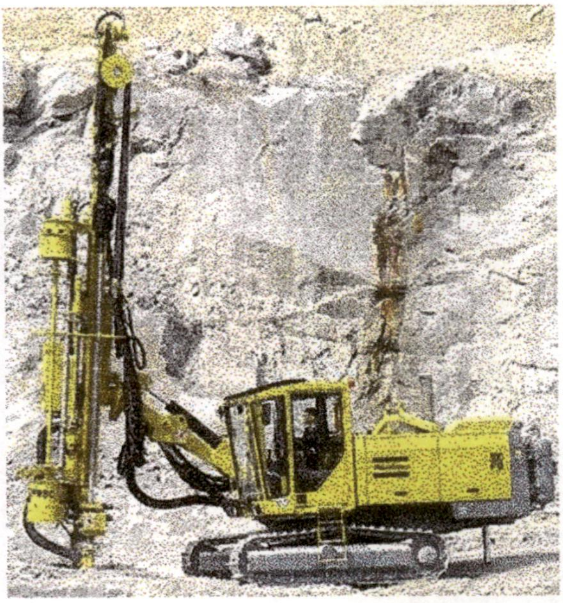


Fig.4.3 *Hydraulic Drill Rig* (32)

Advantages of Hydraulic Drill Jumbo: (7)

1. Safe for drilling crew,
2. Only one operator and one mechanic at heading,
3. Short cycle time, one third of manual drilling,
4. High efficiency. About 50 to 60 % of primary energy transmitted to rock,
5. For long tunnel adequate electric cable and transformer will eliminate loss of energy,
6. Smooth operation,
7. Direction depends on a skilled operator. Optional computerized operation ensures perfect drill pattern and 90 % to 95% pull could be achieved.
8. Over cut minimum.

Disadvantages of Hydraulic Drill Jumbo:

1. High initial cost,
2. Not suitable for tunnels less than 3m diameter,
3. Highly skilled personnel and excellent job facilities required,
4. Detailed study of rock type, tunnel size and length of tunnel is required.
5. Equipment, tools and spares are imported and not readily available,
6. Drill hole size from 38mm and above may not always match standard galantine of 25mm.

4.2.2. Rock Bolting Equipment.

Rockbolting is a well-established tunnel supporting system in any of rock. There are several types of rock bolts, that could be *pre-tensioned, post-tensioned, ordinary grouted bolts or rock anchors* and *friction type* rock bolts. The pre-tension or post-tensioned rock bolts are designed to create a compressive ring around the tunnel rock periphery, which will help the tunnel to become self-supporting. Ordinary grouted rock bolts or rock anchors and friction type rock bolts are provided to prevent any further rock loosing or de-stressing and the inherent compressive stress of peripheral rock strata is sufficient for creating a self-supporting ring around tunnel.

The length of rock bolts is decided according to the *diameter* of the tunnel. A length of 3m to 4m and diameter of 25mm to 28mm is most common. The matching drill hole diameters of 32mm to 38mm are sufficient to provided all type of bolts. Previously the drill holes used to be provided by Jackhammer and the rock bolts used to fitted and fixed manually. This system is *slow, hazardous* and *unreliable*. In modern insert the resin capsule, pick up the rock bolt, insert the bolt, rotate and tighten the nut etc. Other facilities like grouting or applying hydraulic pressure inside the *swellex type rock bolts* to expand to desire diameter are also provided in the machine. (7)

Fig.4.4 *Robolt 320 bolter with mechanized* ***screen*** *handling. Tamrock offers a full range of mechanized bolting rigs covering most bolt types and applications.* (33)

Advantages rock bolting operation by Hydraulic *Rockbolter*:

- Operation is safe,
- Entire operation is mechanical and almost 100% reliability is ensure,
- Ensures short cycle time, entire operation is over well within stand up time of rock.

4.2.3. *Scaling Equipment.*

When hydraulic jumbo and hydraulic rock bolter are used, the *hydraulic machine scaler* (**Fig.4.5** & **Fig.4.6**) is to be used for scaling of loosened rocks immediately after the blast and or mucking. The vibration intensity caused by the hydraulic drill jumbo is very heavy and may result in rapid loosening of cracked rock, which cannot be scaled, and removal by manual scaling.

A mechanical scaler should compulsorily replace manual scaling, as scaling operation is primarily required for insuring safety of persons and equipment.

Fig.4.5 *SBU-800. The machine especially for high capacity mechanical scaling is by far the most advanced piece of machinery used in underground mining.* (27)

The SBU-800 is the state-of-the-art mechanical machine for underground mining and tunneling. SBU machines are designed and constructed to enable as safe and comfortable a working environment as possible and offer safe scaling for mines.

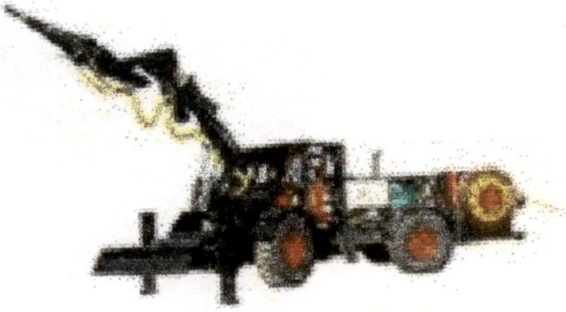


Fig.4.6 *SBU 800 – the machine for safety that reaches even further.* (27)

4.2.4. Shotcreting Equipment

Shotcrete or spray concreting is the latest tunnel supporting system and is widely used in good to fair categories of rock. With rapid development of modern tunneling technology, *shotcrete in combination of rock bolts* are being successfully used in any types of rock in tunnel. Ready mixed concrete is projected under pressure with a very high velocity through a pipe and nozzle for application on the rock surface to form a layer of *50mm to 150mm* thick on rock surface.

Shotcrete strengthen the rock characteristics and prevent loosing and rock fall. The concrete ready mix could be *dry or wet type*. For dry type, quick setting compound in the form of powder is pre-mixed in the batch and the water of desired quantity is added in the nozzle during application. For wet mix, the water and liquid quick setting compound are added in the nozzle.

Modern machine in tunnels (**Fig.4.7**) are mostly designed to use *wet mix* and a specially calibrated *dosage* devise inject exact quantity of quick setting compound as desired in the design mix. Shotcreting are often applied after the rock surface is covered with *chain link* or *welded wire mesh* to induce additional tensile and shear resistance to the shotcrete layer. In the latest technology *steel fibers* or *poly fibers* are added in the mix to achieve desired result. (7)

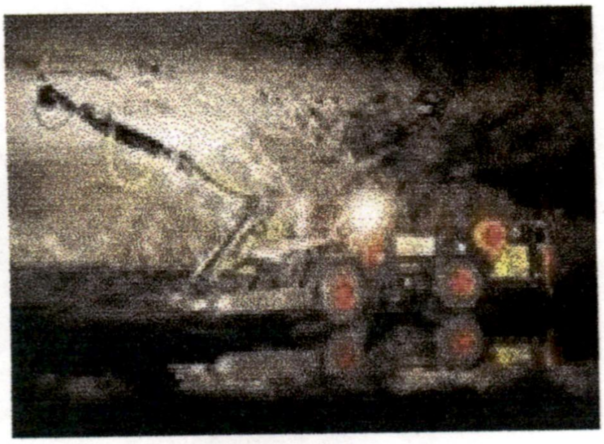


Fig.4.7 *Shotcreting robo-arm. CSU 800 – the only serious choice for all the shotcreting requirements, with the same level of excellence in the areas of operator comfort and safety.* (27)

Advantages mechanized operation with hydraulic *robo-arm* include:

- With the new CSU 800 several improvements in quality have been achieved as well as more uniform thickness of the shotcrete,
- Calibration of accelerator mix from the cabin, improved mixing system plus better air mix allows a higher compressive strength on the shotcrete,
- Increase in productivity,
- Equal quality,
- Safe in any application,
- High quality with strict control of w/c ratio can be maintained,
- Minimum rebound,
- Application is *8 to 40 cu.m per hour,* short cycle time.

- Minimum rebound,
- Application is *8 to 40 cu.m per hour*, short cycle time.
- Very short cycle time ensures supporting well with in the stand up time of rock.

4.2.5. *Mucking and Hauling Equipment*

Equipment for mucking and hauling generally can be grouped into three types as follows:

- *Rail Mounted,*
- *Tire Mounted,*
- *Crawler Mounted (for mucking only),*

For a small diameter tunnel, rail mounted equipment is preferred. For a large diameter tunnel, say 6 m and above, both options are to be examined with respect to availability of resources. Crawler mounted mucking machines can match both with the rail and tire mounted haulage equipment. When both the options are there, the following factors are to be considered for deciding one of the alternatives:

Rail Mounted	*Tire Mounted*
▪ Capital cost is high but operation and maintenance cost is low.	Capital cost is comparatively less but operation cost and maintenance cost is very high.
▪ Exhaust gas and smoke hazards are low. Ventilation system does not involve any major cost.	Exhaust and smoke hazards are very high. Need high capacity and efficient ventilation. In addition, special engines are to be fitted in the loader to emit minimum hazardous gas.
▪ Breakdown level is low.	Breakdown level is higher.
▪ Cannot operate in steep gradient,	Can operate in steep gradient.
▪ Lesser population and production. Spares are not readily available.	Large production from various manufactures. Spares are readily available at reasonable cost.

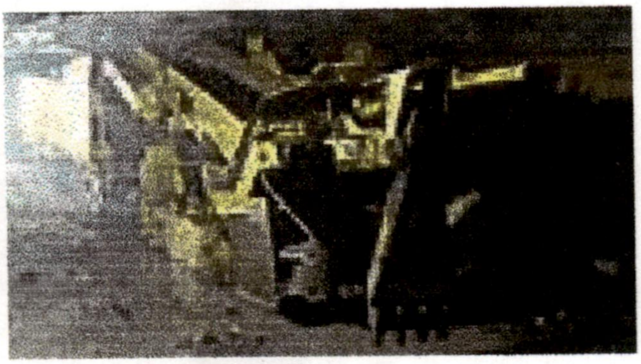


Fig.4.8 *Hydraulic excavator with conveyor* (27)

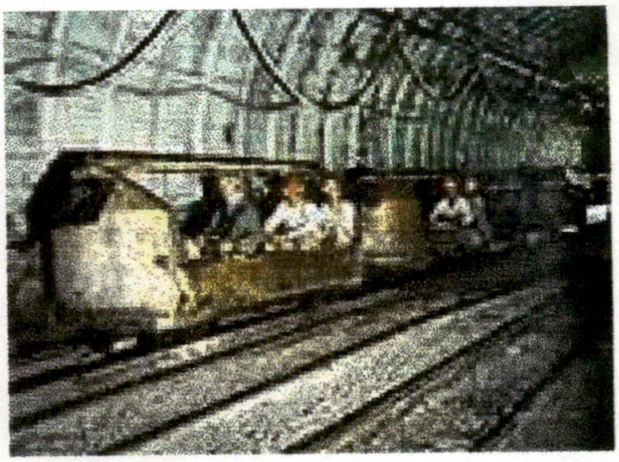


Fig.4.9 *Loco – Mine cars* (35)

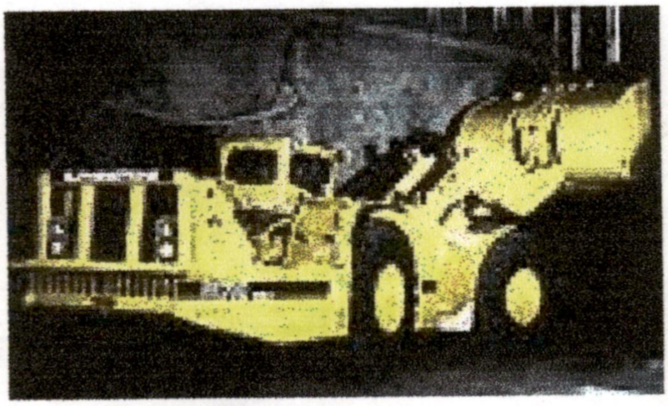


Fig.4.10 *LHD Loader (Tire mounted).* (33)

Fig.4.11 *Low bed dumper haulage,* provide *for waste.* (33)

The mucking and hauling equipment has to work together. Following combination of mucking and hauling equipment are commonly used,

1. Rail Mounted

   Hydraulic excavator with conveyor and Loco-Mine cars.

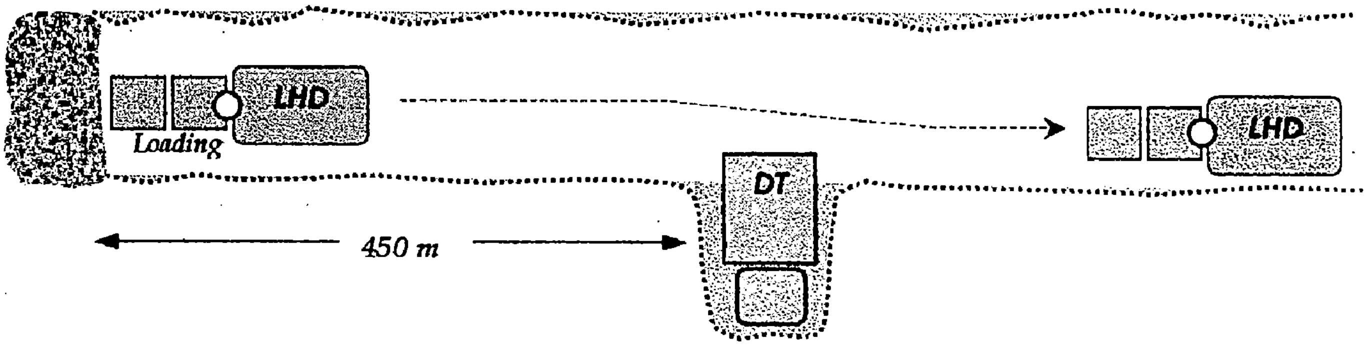
2. Tire mounted.
   a. Loader with low bed reversible dumpers.
   b. Loader with conventional dumpers. The tunnel must have a niche at every 250m to 300m to reverse the dumpers.
   c. Crawler mounted hydraulic excavator with low bed dumpers.

d. Crawler mounted hydraulic excavator with conventional dumpers. Tunnel must have a niche at every 250m to 300m reverse the dumpers and loader.

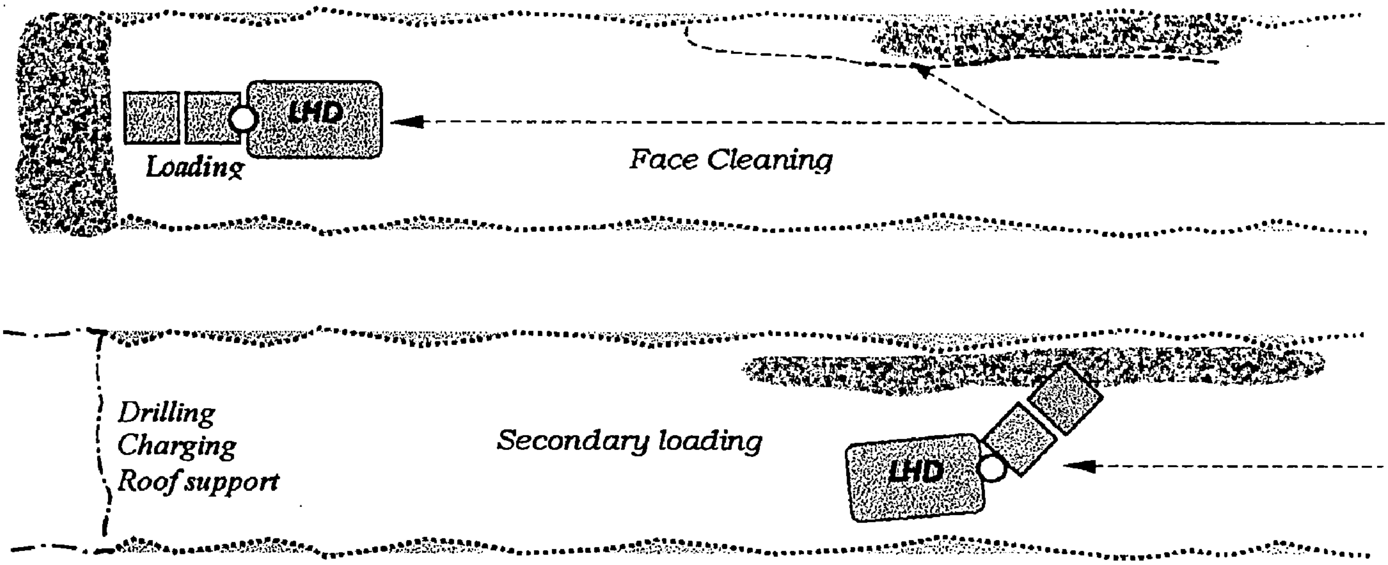
For a very large diameter tunnel, say 10 m diameter and above, a niche may not be required where loaders and dumpers can reverse at any point in the tunnel. (7)

The illustration of mucking and haulage are shown in figures bellow:

1. *In narrow tunnel heading/turning niche:*



2. *Loading in large tunnel without loading niches with one LHD-machine*



The maximum tunnel inclination for LHD-loader and rubber-tired jumbo is approx 15°-20°. In greater inclination, or when the tunnel floor is especially uneven, crawler based units can be used.

4.2.6. Drilling Time and Tunnel advance Estimate.

An example of drilling and tunnel estimate in Himalayas conditions is given below:

No.	Description	*Sheared rock*	*Higly sheared rock*	*Modified jointed Rock*
1	Face area	51.9	51.9	51.9 m^2
2	Height	8	8	8m
3	Width	8	8	8 m
4	Profile length, excl. bottom	20.6	20.6	20.6
b.	*Drilling Equipments.*			
	Drilling system			2 boom + 1 basket (Drill jumbo)
1	Feed length, total	5270	5270	5270 mm
2	Drill steel length	3700	3700	3700 mm
3	Max hole length	3.44	3.44	3.44 m
4	Number of booms	2	2	2
5	Coverage, height	8.51	8.51	8.51 m
6	Coverage, width	12.82	12.82	12.82 m
c.	*Drilling Data.*			
1	Hole diameter	45	45	45 mm
2	Cute diameter	Parallel	Parallel	Parallel
3	Reamer hole diameter	102	102	102 mm
4	Number of holes	99+2	99+2	99+2
5	Average hole length	1.7	1	0.3 m
6	Drilled meters	175	103	340 m/round
7	Pull length	90	90	90%
8	Advance	1.5	0.9	3.0 m/round
9	Specific drilling	2.2	2.2	2.2 drm/m^3
d.	*Drilling Time*			
1	Type of rock	Shale	Mudstone	*Sandstone*
2	DRI	65	75	52
3	Density	2.6	2.5	2.6 t/m^3
4	Rigs parallel in tunnel	1	1	1
5	Number of operator per rig	2	2	2
6	Operator experience	Advance	Advance	Advanced
7	Penetration	2.15	2.43	1.78 m/min.
8	Drilling rate	1.06	0.81	1.23 m/min
9	Reaming penetration	0.8	1	0.7 m/min.
10	Reaming time	9	7	7 min.
11	Drilling time include reaming	88	67	75 min.
12	Auxiliary time	15	15	15 min.
13	Drilling cycle	103	82	90 min.

e. *Charging Time*

1	Charge total	113	56	241 kg.
2	Special charge	1.42	1.21	1.57 kg/m^3
3	Charging capacity	140	140	140 kg/man/hr
4	Charging crew	3	3	3
5	Charging cycle	56	48	84 min/round

f. *Loading Time*

1	Equipment	LHD	LHD	LHD
2	Bucket size	2.7	2.7	2.7 m^3
3	Average carrying distance	10	10	10 m
4	Loading + hauling capacity	120	120	120 m^3/hr (loose)
5	Swell factor	1.6	1.6	1.6
6	Over break	40	40	40 cm
7	Total volume	154	91	299 loading m^3/round (loose)
8	Loading cycle	92	60	164 min/round

g. *Bolting Time*

1	Rock bolts/row			with *Robolt*
2	Rock bolt spacing			0.75 m
3	Rock bolts/round			24
4	Rock bolt length			4 m
5	Type			Mechanical
6	Bolting cycle			104 min

h. *Concrete spraying time*

1	Sprayed concrete thickness	50	50	50 mm
2	Total volume per round	2.8	1.7	5.5 m^3
3	Working capacity	5	5	5 m^3/hr
4	Concrete spraying cycle	64	50	95 min

i. *Other Cycle Times*

1	Arches + wire mesh	90	135	30 min
2	Blast and ventilation	30	30	30 min
3	Scaling + clearing	45	45	45 min
	Miscellaneous			

j. *Working time*

1	House per shift	8	8	8 hours
2	Effective time	6	6	6 hours

3	Shift per day	3	3	3
4	Work day per week	7	7	7
5	Work day per month	30	30	30 days
6	Working days per year	340	340	340 days/year.

k. Performance

1	Average round cycle time	479	449	710 min
2	Round per day	2.25	2.4	1.52 round/day
3	Daily advance	3.44	2.16	4.5 m/day
4	Weekly advance	24.1	15.1	31.5 m/week
5	Monthly advance	103.3	64.8	135 m/month
6	Yearly advance	1170.5	734.4	1530 m/year.

l. Practical Excavation Time.

1	Tunnel length	1000	1000	1000 m
2	Long term efficiency	70%	70%	70%
3	Practical Excavation time	415	661	317 days
		59.3	94.5	45.2 weeks
		13.8	22	10.6 months

4.3. TUNNEL BORING MACHINE (TBM)

The tunneling machine or the *'mole' is a self-contained unit combining the functions of rock cutting, muck disposal and tunnel supporting.* In general, the mole is built-in with a circular cutting head, on which are mounted the cutters or bits. The machine is equipped with electric motors that furnish power for rotating the cutter head and furnish hydraulic pressure to a system of jacks. These jacks are used to absorb the torque effect created in the machine, maintain pressure on the tunnel face and move the machine forward by gripping the sides of the tunnel, if the tunnel requires support, the jacks can also thrust against these supports.

As the bits cut into the tunnel face, rim buckets, mounted on the cutter wheel, pick up the cuttings and discharge them radially to the center and on a conveyor belt. This conveyor then discharges the muck either on another conveyor or into muck cars, which are hauled out with locomotives as in the conventional methods of tunneling.

In ground conditions where the stability of the ground requires their use, shields are used with tunneling machines to maintain the tunnel sides and roof until supports are erected. To aid in handling of these supports, cranes and other handling systems are provided. In order to minimize the support erection time, erector arm assemblies are incorporated on the machine so that the support can be placed in position by mechanical means speedily.

To control dust, the machines are provided with *spray nozzles* positioned on the front of the cutter-head to provide a water-detergent-mist mixture.

To control alignment, lasers are incorporated on the machine.

4.3.1. Classification.

Moles may be classified according to the following three principles:

1. *Type of material to be mined.*
2. *Cutting principle employed* and,
3. *Cutter head movement.*

Each one of these is described separately.

4.3.1.1 Type of material to be mined.

Two broad classes of machines are:

a. *Soft ground tunneling machines* and
b. *Rock tunneling machines.*

In soft ground tunneling machines, the cutter-head is protected with a tunneling shield and in this machine tooth type of cutters are normally employed for obtaining the cutting action. The rock-tunneling machine on the other hand may or may not be provided with a full shield. These machines may have any type of cutters like *disc, roller, gauge* or *button* depending upon the manufacturer, and the characteristics of rock.

4.3.1.2 Cutting principle employed.

Two principles are employed in disintegrating rock. Based on these the machines are classified as:

a. *Machines breaking rock in compression*, and

b. *Machines breaking rock in tension.*

While most of the machines use the thrust applied against the tunnel face and the simultaneous rotation of cutter-head to crush the rock and form the muck, certain machines have been developed in which a cutter-head of a smaller diameter, oscillating on a beam, is first sunk some distance into the tunnel face and then rotated in any desired spiral form to break the rock in tension. This cutter-head has tooth bits on the front and on the sides for sinking and cutting operations respectively.

4.3.1.3 Cutter-head movement

Base on movement of cutter-head, machines are classified as:

a). *Rotary type*, and

b). *Oscillating* type.

Each of these is described separately in the following paragraph:

a. Rotary type moles.

This type usually consists of a wheel fitted with either disc cutters or roller bits, the wheel revolving round a central shaft. This type may be further sub-classified as:

i.) *Jumbo machine,*

ii.) *Shield machines* and

iii.) *Gripper machines*

There is some degree of overlap of features of these machines. For example, most of the Jumbo and Gripper machines also incorporate some kind of a shield. This may be a small segment at the center of cutter-head support usually called a canopy, or almost a full shield with an overhanging tail under which tunnel ribs can be assembled.

One feature incorporated in machines of all categories is a rotating cuter-head incorporating the cutting elements and buckets for muck pick up. The cutter-head is mounted on a cutter-head support, a non-rotating structural member mounting the cutter-head bearing and seals, and on some machines serving as the front vertical support and side steering support.

i) Jumbo machine

These machines are usually large size 7.62 m (25 ft) and above in diameter (*Fig.4.12*). The cutter-head support is attached to the forward end of a structural steel framework resembling a conventional drill jumbo. This type of machine is usually *used in soft rock* when ring beam supports are specified or expected throughout the tunnel. The jumbo is supported at the rear by equalizing trucks on heavy rails. This rear support is hydraulically mounted on the jumbo to provided vertical and lateral steering. The jumbo provides working decks for the mole's electrical and hydraulic equipment, minor repair shop space, and storage for roof support equipment. The top deck is provided with a ring beam segment transporting system and a hydraulic positioner, which places the segments on the rotary ring beam jig.

The jig provides a mechanical assembly of the quarter ring segments immediately behind the cutter-head support without interrupting the machine's advance. Rings can be assembled as close as one quarter of the diameter from the face where the rock is being cut. This closeness of support has been found to be critical in large diameter soft rock tunnels.

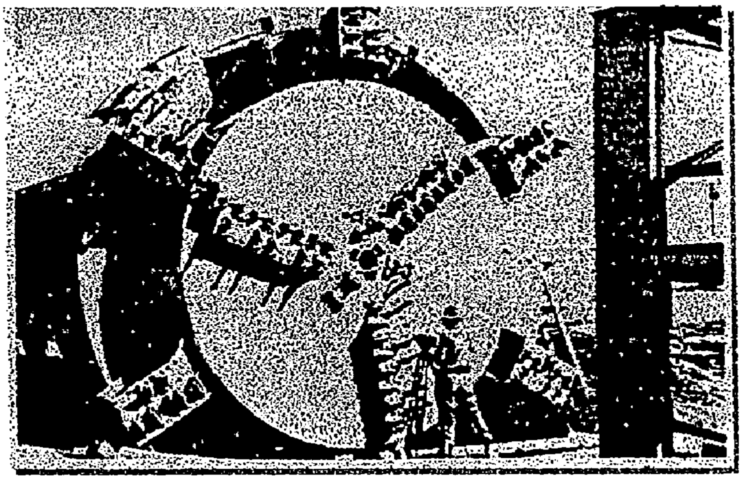


Fig. 4.12 *Type: Jumbo, Model: 910, 400 hp, Diameter: 25′ 9″, Rock Type: Shale*(21)

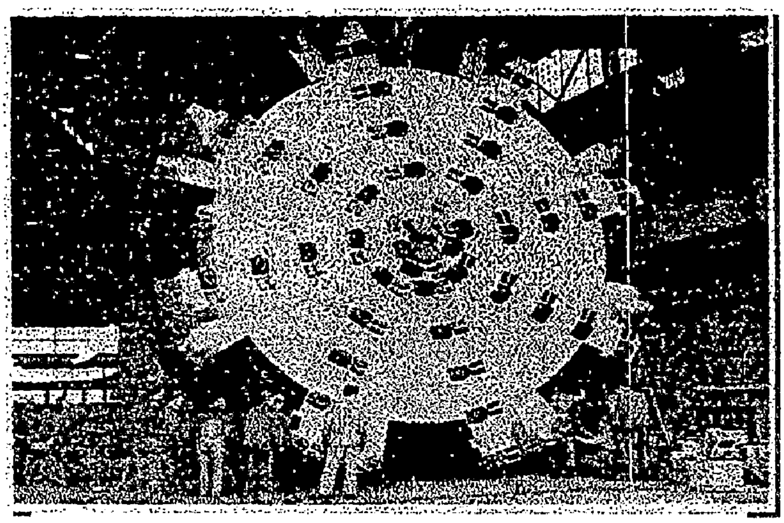


Fig. 4.13 *Type: **Jumbo**, Model: 351, 680 hp,*
Diameter: 29' 6", Rock Type: Shale (21)

ii) Shield machines

Shield type tunnel borers consist of a more or less conventional shield with thrust rams and an erector system. The cutter-head and cutter-head supports are contained within the shield in place of the work platforms and breast board supports.

Shield machines are usually used *in non-rocks formations*. This may be a competent, cohesive, relatively self-supporting soil like the clays, or it may be cohesion-less running material like sand and gravels. Mixed condition may be encountered in many situations. More than 80 shield type tunnel borers have been built by at least 25 different manufacturers around the word. This type of machine is shown in Fig.4.14 (21)-p.6

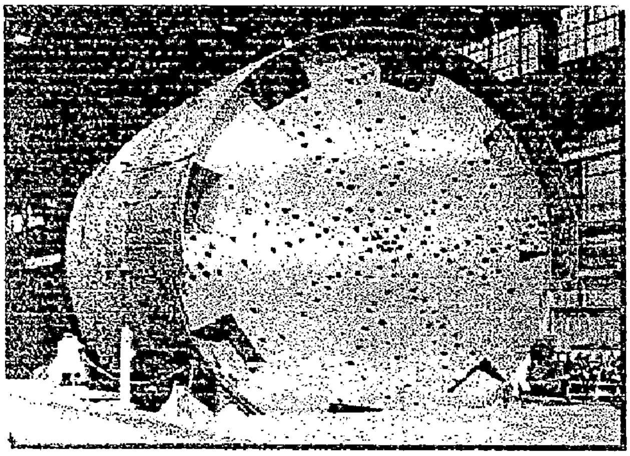


Fig.4.14 *Type: **Shield**,*
Model: 341, 1000 Hp,
Diameter: 33'10"

Fig.4.15 *Telescopic Shielded type machine* (27)

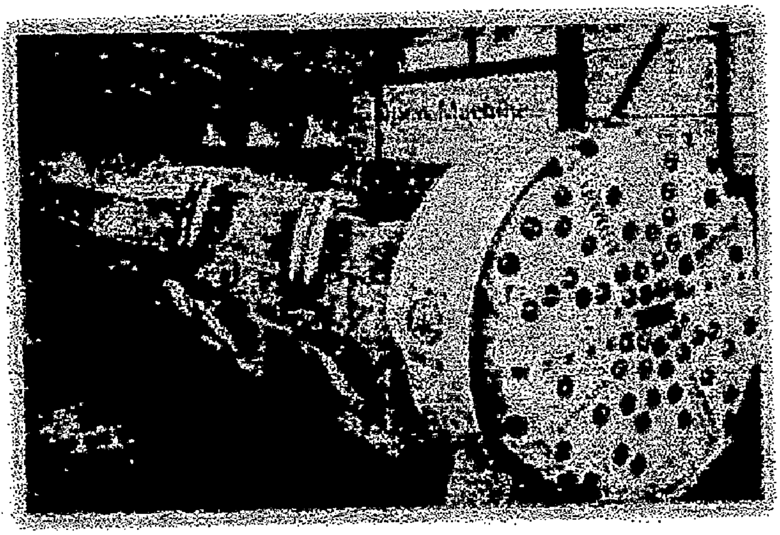


Fig.4.16 *Open Machine of TBM* (27)

iii) Gripper machines

Gripper type tunnel borers (Fig.4.15 and Fig.4.16) are *used in rock* which is relatively self supporting or competent. These are built to provided some degree of initial support in cases where poor soil formation is encountered and provides the means to install ring beams or rock bolts close to the face.

If the rock requires ring beams ahead of the grippers, the tie bolts at the side are left out so that when the gripper is retracted, it steps over the rib and grips between the two ribs that were placed ahead. Should the ground become so bad that the grippers cannot be used effectively against the walls, they can be used to react against the forward edge of the ribs like the propulsion system of the jumbo machines. This of course, requires collar bracing between a numbers of ribs to the rear so that the thrust reaction can be transferred into the tunnel walls through the blocking.

This machine is normally articulated in the middle so that it can bore around short radius curves. (21)-p.7

b. Oscillating type

The oscillating type of mole is intended primarily *for soft* or *semi-stable formations* including *clays, silts, sand* and *gravels*. The cutting arms are mounted on two or more separate shafts close to the center of machine. The arms work independently of each other, much in the same fashion as automobile windshield wipers.

Another distinguishing feature of these machines is the forward slope of its shield. The overhang is designed to maintain the stability of the tunnel face and to keep the cutter arms from becoming clogged by a sudden clip page of material.

4.3.2. Basic Functions in a Tunneling Machine.

All tunneling machines are provided with the following basic systems for their operation.

4.3.2.1 Power System.

Electric power is the main drive, which is fed through suitable extendable electric cables and is stepped down on the machine with the help of transformers to suit the drive motor voltage requirements.

4.3.2.2 Hydraulic System.

Electric motors may then be used to drive the pressure generating system of the hydraulic rams, which at the same time support the machine against tunnel walls or supports.

4.3.2.3 Cutter-head.

This is the *main component* performing the cutting action. The cutter-head may be a circular disc mounted with cutters of various types or it may have spokes which mount the drag pick type of cutters. The cutters may be of *disc, gauge, button* or *drag picks* type and their performance depends upon the material used and the design.

4.3.2.4 Muck Removal System.

The cutter-head is provided with buckets all around its periphery suitably spaced which scoop up the muck and discharge into a hopper at the top, which further discharges onto a belt conveyor. There may be one or two systems of belt conveyors leading the muck to the trailing end of the machine where it is filled in dump cars to be hauled out by locos as in conventional method.

4.3.2.5 Tunnel Support System.

For immediate support, the tunneling machines are provided with *shields* and *suitable platforms* and arrangements on these machines facilitate rapid erection of ribs or wire net or even *shotcreting* can be done where required.

4.3.2.6 *Tunnel Guidance System.*

For line and grade control the tunneling machine are provided with *Lasers*. Electronic positioning system are used to control the direction of boring. *The Global Positioning System* (*GPS*) is rapidly becoming the standard surveying for determined 3-D positioned accurately. (2)

4.3.3. Method of Operation for Hard Rock.

The various types of moles described under classification have a number of common operational characteristics. However, the performance of individual machines as suitable the Himalayas condition is described as *Alkirk Hard-Rock Tunnel* show in Fig.4.17.

This mole manufactured by M/S *Ingersoll Rand* of U.S.A has been successfully used to drive the *Port Huron* fresh water tunnel in Michigan. The boring machine tunnel data is given below: (12)

a. *Tunnel length* = *31,555 ft. (9618 m)*
b. *Bored diameter* = *18'4" (5.6 m)*
c. *Type of rock* = *shale, limestone boulders*
d. *Rock compressive strength* = *9,000 to 30,000 psi (633-2110 kg/m*^{2}*)*
e. *Cutter-head H.P* = *750 HP*
f. *Total H.P* = *1085 HP*
g. *Cutter-head (rpm)* = *72 rpm*
h. *Pilot bit (rpm)* = *60 rpm*
i. *Maximum thrust* = *1.5 million lbs. (675 ton)*
j. *Maximum torque* = *575,000 lbs.ft. (78867 kg.m)*
k. *Nominal hydraulic pressure* = *2,000 psi. (140 kg/m*^{2}*)*
l. *Max hydraulic pressure* = *3,000 psi. (210 kg/m*^{2}*)*
m. *Electric specifications* = *13,200/480 V, 3 phase, 60Hz*
n. *Started* = *October 1969.*
o. *Finished* = *December 1970*
p. *Best boring rate* = *19 ft/hour (5.8 m/hr)*
q. *Average boring rate* = *13.7 ft/hour (4.17 m/hr)*
r. *Weight of the machine* = *500 tons*
s. *Cost of the mole* = *$ 1.5 million ≈ Rs.7.5 crores*

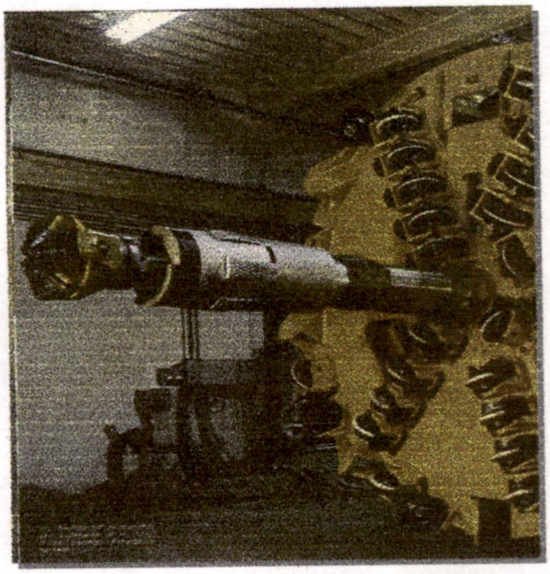


Fig.4.17 *Pilot bit, pilot anchor and cutter-head of an 18'4" (5.59m) diameter I-R hard-rock tunneler* (12)

The *Alkirk* tunneler has three basic sections, the *tunneler assembly, the power train and the auxiliary trailer,* all of the which ride on 24x36 in. steel skids except for two steel wheels in the front. The front end of the mole has *thirty* 12-in. diameter-*carbide tipper cutter wheels* that chip rather than pulverize the rock. Muck size average about three inches, which in the shale that was encountered was an important consideration. The larger chunk mean that swell in the material is reduced from over 100 % to 70%, cutting down on the volume of spoil.

Five gauge cutters, also with *carbide tips*, are tips, are mounted at a 45-degree angle on the big wheel's perimeter. Two and three row cutters are mounted alternately to provide constant cutting action. The manufacture claims, it is the first Mole maker to use all carbide cutters and when the contractor first started boring he hoped a set of cutters would last between 76 m (250 ft) and a mile, but at 1130 m (3705 ft) mark, only less than half the cutters had been replaced.

The cutter-head has a boring capacity of 5.8 m (19 ft) in protruding 3.35 m (11 ft) ahead of the main cutter-head is the pilot bit and the pilot anchor assembly, key to the machine's design (*Fig. 4.17)*

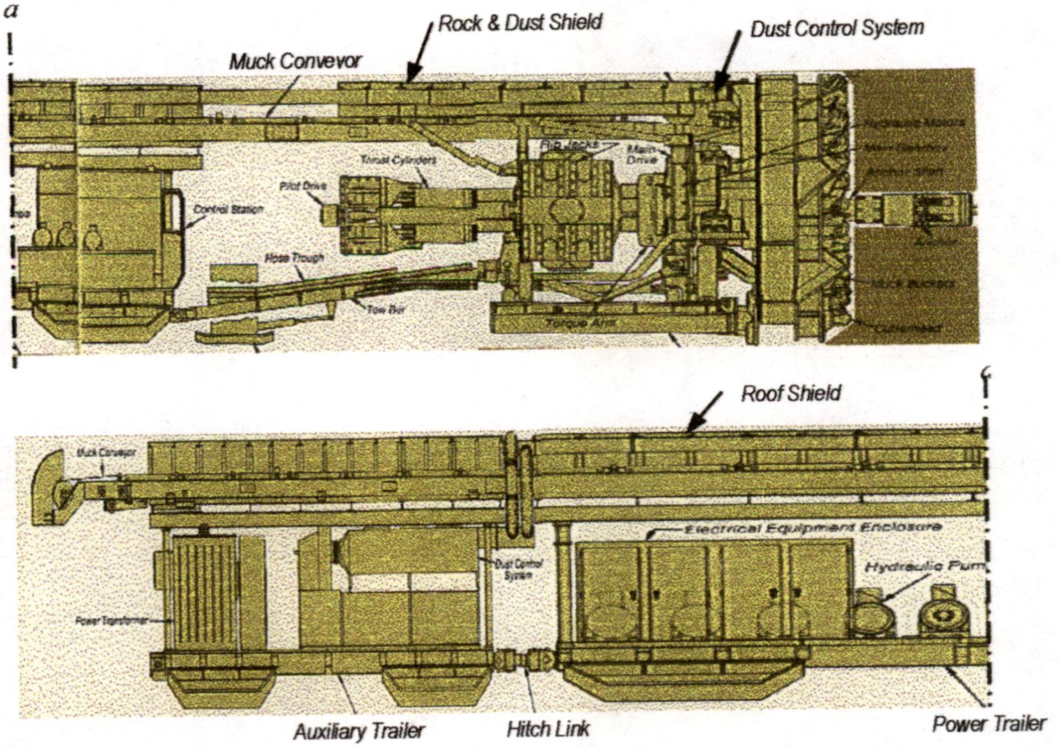
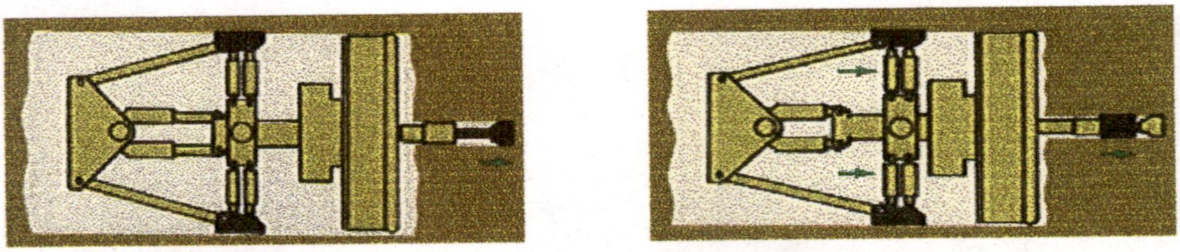
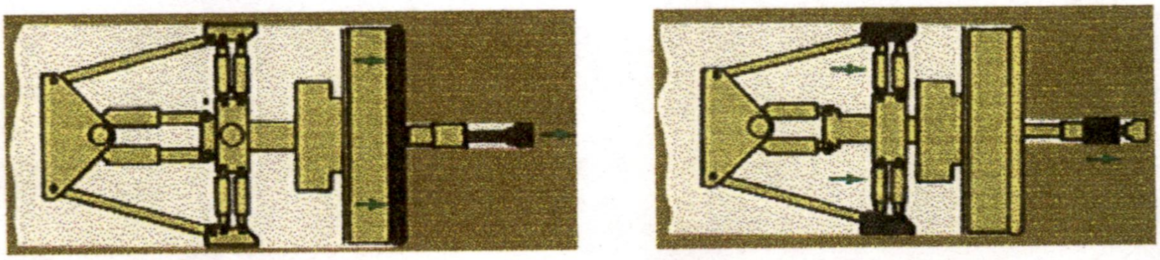


Fig.4.18*de elevation of typical three-section Ingersoll-Rand tunneler* (12)



Pilot bit drills into tunneler face as rib jacks supports tunneler.

Pilot anchor and rib jacks advance.



Pilot anchor locks into pilot hole and rib jacks support cutter-head shaft. Pilot bit and cutter-head bore simultaneously.

Pilot anchor and rib jack advance again, cycle is ready to repeat.

Fig.4.19 *How the Ingersoll-Rand Tunneler works* (12)

The unit's cycle (Fig.4.19) begins when two 123 *kg/m²* (1750 psi) horizontal rib jacks extend against the tunnel walls to support the mole as the pilot bit drills the lead hole. Next smaller auxiliary jacks extend to support the machine, the rib jacks retract, and the pilot anchor and rib jacks (mounted on a common shaft) advance together inserting the pilot anchor in the lead hole. The pilot anchor expands hydraulically, the auxiliary jacks retract and the mole is ready to mining. As the main cutter-head advances 60cm (2 ft), the pilot also bores ahead by 2 ft. Lawrence Division liken this arrangement to a T-shaped arbor, supported by the pilot anchor (acting like a 24 inch diameter rock bolt) and the two rib jacks, about which the cutter rotates.

The cutter-head rotates at 7.2 *rpm* chipping the rock down onto metal plate scrapers mounted on the face of the cutter-head that shunt the muck into 10 cutter-head buckets. The buckets discharge to a 90 cm (36 in) wide, 23 m (77 ft) long conveyor.

A metal dust shield with rubber flaps to accommodate the curve of the tunnel keeps all dust in front of the cutter-head. Suction pulls dust and smaller particles of muck into a cyclone, which feeds the dust into a water scrubber, eliminating it, and returns the residue to the front of the cutter-head. This main conveyor feeds a secondary conveyor belt 60 cm (24 in) wide and 45 m (150 ft) long that loads muck trains operating through a California switch.

The mole is completely hydraulic. Five double piston type radial motors on the main cutter-head provide *675,000 kg* (*1.5 million lbs*) of torque. Electronic motors run the piston and vane type pump that feed the hydraulic motors. *Three 250 hp.* motor runs the three pumps for the main cutter-head, one 150 hp. motor run the vane pump for the pilot bit; and three 20 hp. motors provide power for thrust, suspension, rib jacks, pilot thrust, pilot anchor and vertical and horizontal steering. A topside generating station supplies power for these motors.

A laser beam is used to control the machine thus keeping it on the alignment. A mirror on the front of the mole reflects the beam to a target for manual operation. For automatic control, the beam is reflected onto a set of ⅛ x ¼ in. *photoelectric cells* connected to a servo valve that controls the horizontal and vertical steering rams.

Methane detection system with stations in the ventilation exhaust line and up near the tunnel roof not only warns of trouble, but also shuts down all electrical power automatically.

The other type of Tunneling Boring Machine as suitable for Himalayan condition also described by *The Robbins Company* used *Hard Rock Rotary Machine.*

Gripper-type tunnel borers are used in rock, which is relatively self supporting or competent. Robbins gripper machine are built to provide some degree of initial support in case bad ground is encountered, and means are provided to install ring beam or rock bolt to the face.

The Robbins Company of U.S.A had been successfully used to drive the defy bad ground at *Walgau Hydro Tunnel in Austria.* The project information is given below:

a. *Tunnel length* = *32,000 ft. (9,756 m) and 34,000 ft. (10,366 m).*
b. *Rock Description* = *Dolomite, Siliceous Limestone, Flysch.*
c. *Unconfined Compressive strength.* = *18-20 ksi (1265-1406 kg/cm²)*
d. *Support* = *Precast Concrete Segments/ Ring Beams.*
e. *Machine Type* = *Hard Rock Rotary Machine.*
f. *Diameter* = *20' 5" (6.25 m).*
g. *Horse Power* = *1200 HP (895 kw).*
h. *Thrust* = *871,000 lbs (792.000 kg)*
i. *Weight* = *298 tons (270 metric tons)*
j. *Cutters* = *44 – 15.5 (394 mm) Single Disc Cutters.*

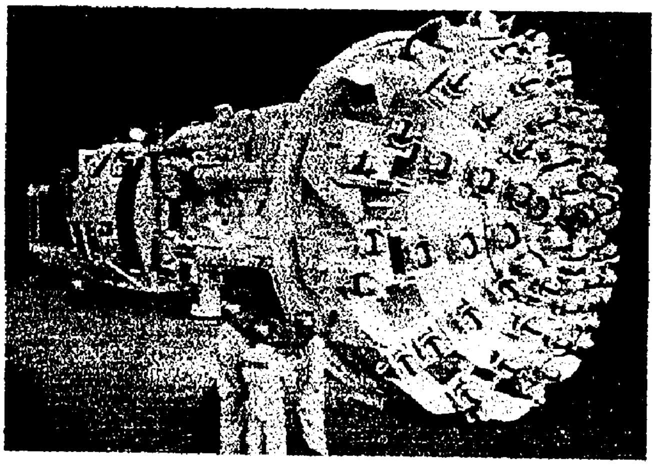


Fig.4.20 *Hard Rock Rotary Machine.*
20' 5" (6.25 m). Type: Gripper, 1500 hp

A pair of near-identical 6.25 m diameter *Robbins Tunnel Boring Machine,* after fighting off faulty ground, cave-ins and heavy water tunnel bore in Austrian Alps, completed the tunneling nearly 9 months ahead of schedule.

For most of its length, the tunnel travels through mixed and faulted geology. There are several types of *dolomite limestone, gneiss, sandstone, marls and shale,* all in sloping formation and interspersed with large and small watercourses. The incompetent ground required the frequent placement of roof bolts and ring beam. To accomplish this, *Bohler* roof bolting chain feeds on sliding carriages were mounted behind the cutter-heads, permitting rock drilling and bolt placement while the TBM progressed. An arm erector on the 204-215 Robbins TBM and a ring transport and ring erector on the 204-216 machine handle ring placement. A shotcrete seal was applied from staging immediately behind both TBM's. The long bore was excavated from two location and three headings.

In the process of completing the 21 km tunnel, contractors succeeded in coaxing their TBM's through very poor and excessively wet ground. They likewise made remarkable progress through competent formation with advances of from 40 to 50 m per day common. Together, they excavated some 640,000 m^3 of rock.

The 44 single disc cutters on each of the Robbins cutter-heads were replaced on an average of one cutter per 15 m of driven tunnel, giving an average cutter set life of 660 m.

The completed bores, with the numerous faulted and unsound section strengthened and sealed with ring beam, mesh and *shotcrete*, will be lined throughout, reducing its 6.25 m bored diameter to 5.45 m. the *precast* invert segments, which supported the mucking railway, will remain in place as the termination point for the 400 mm thick seal and lining.

4.3.4. A Case for the Use of Tunnel Boring Machine on Himalayas.

On a typical *Hydel* project in India, the longest lead time is generally the construction of the tunnel – average advance rate 1.5 m/day, and this factor also tends to conditions one to accept slow rates of advance on associated work such as shafts, which could also be mechanized.

Throughout the world *Hydel* tunnel are being driven by *TBM*'s in both hard rock and mixed faulted geology, *viz*:

- *Mica schist* and *trondhjemite* 100-210 Mpa. in Norway. Two tunnels total 13 km at average advance rates of 22 m/day, and
- *Dolomite limestone, gneiss, sandstone, marls* and *shale* – 28.275 Mpa. in Austria. Two tunnels total length 21 km at average rate of 20 m/day.

Full-face rotary machine should be considered only if they can provide an economic or time advantage over conventional mining methods. Generally, this must be calculating for each individual project. Machine manufacturers and contractor can provided economic-time studies to evaluate the practically of a tunnel machine on a given project.

"Rules of thumb" can often be quite misleading. However, the following are offered to provide a list of items to be evaluated when considering purchasing a new tunnel machine: (9)

1. Tunnel length = Greater than 2 km further works foreseen.
2. Tunnel diameter = Minimum 2 m, present maximum 15 m.
3. Rock strength = Under 300 Mpa.
4. Geologic structure = Bedded, jointed, blocky, abrasive, etc.
5. Tunnel turn = Minimum about 100 m radius.
6. Tunnel grade = -18° to about +45°.
7. Maximum water inflows (at face) = 10 m^3/minute/m of dia.
8. Maximum water pressure = 15 bar.
9. Maximum ground load = about 50 t/m^3.
10. Power (electrics) = is adequate power available.
11. Shaft size and hoisting capacity = Can it handle the largest-components ?

Robbins machines today can be designed to fit mine dimensions at about 1.2 × 3.3 × 8 m, with maximum weight of one piece below 15 ton. *Full-face rotary* tunnel machines offer many advantages in economy, safety and speed over conventional drilling and blasting.

When conventional drill and blast method are used to develop a heading, explosives disturb the ground. This will create fissures and open existing cracks which will increase the likelihood of rock falls and allow more ground water inflows. The nature of fracturing rocks with explosive leaves much over break and some "*tight spot*" depending upon the skill of the underground crew. Loose rock must be scaled down, which at best is a hazardous operation.

Full-face rotary tunnel machine, on the other hand, will not disturb the surrounding rock mass. They leave a very smooth and circular tunnel wall offering little resistance to the flow of ventilation air. Ground support requirements are reduced, over-break is minimized, and "*tight spots*" are eliminated with the tunnel machine.

In addition, tunnel machine can develop heading at *two to five times the conventional rates*, provide much safer and more desirable underground working conditions and require less skilled labors than do drill and blast methods. Also the typical noise, flume and dust of drilling and blasting are reduced or eliminated.

4.3.5. Tunneling with Moles

The mole is a full-face tunnel machine as described in details above. These machines having come into the tunneling market as late as in 1954 are now finding an increasing use in construction.

When compared to the conventional method of tunnel excavation, the mole offers definite *advantages*, which can be enumerated as below:

a. *Higher excavation speed,*
b. *Minimal over-break (2.5%), reduces resulting the concrete.*
c. *Fewer personnel required,*
d. *Safer operation, since no blasting is involved.*
e. *Reduction the supports required, since circular section is nearly self supporting and there is less fracturing of rock along the periphery of tunnels, and*
f. *Reduction in the clean up time.*

The mole is not without *disadvantage*. Some of these are listed as follows:

1. High initial investment,
2. Long delivery periods,
3. Machines must be custom made or made to order for the diameter desired, and the characteristic of rock to be encountered. Presently, hard rock barrier has not been broken.
4. Control of dust within safe limits requires a high capacity, well-maintained ventilation system, supplemented with a water spray or fog system on the cutter-head and at transfer points on the conveyor belts, and
5. An accurate guidance system plus expert surveying technicians required maintaining line and grade. A laser beam is being used with fair success now.

Fig.4.21 *Transition from conventional method (drill & blast) section to boring machine tunnel, display difference in quality of hole resulting from two methods.* (12)

Fig.4.22 *Photo showing the smooth curvature obtained, less fracturing and supporting required.* (12)

4.4. RAISE DRILLING.

Currently raise drilling has become the standard method of raising in the *western world*, and it is safety estimated that the majority of raise footage completed in recent years has been by the raised drill method.

The overtake by the mechanized raise drilling method from the older drill-and-shot system has occurred because one or more of the following advantages were apparent to the user:

1. *It was economically more attractive on a direct cost per meter comparison.*
2. *Improved safety because with this method, men are no longer required entering developing rises, so reducing the risk of accidents due to failing rock or the handing of explosives.*
3. *Faster and more predictable excavation method,*
4. *Raise cost per unit length becomes less as raise length increases, offering flexibility in overall mine design.*
5. *Labors reduction,*
6. *Operators can work in a more pleasant environment,*
7. *The method of cutting, rather than blasting, ensures the maximum possible structural competence of the raise and the shape presents good stress characteristics, which are especially important in high-pressure zones or weak ground.*

For example of this, include the *Dinorwic Pumped Storage* scheme (U.K) which involved some 945 m (3,100 ft) of raised boring not only for the main high pressure shaft but additional shaft for:

- *Spillway,*
- *Intake headwork,*
- *Surge chamber,*
- *Main inlet valve gallery relief,*
- *Draft tube valve gallery relief,*
- *Ventilation,*
- *Machine hall mucking.*

At the Victoria Dam project in Sri Lanka, three shaft totaling 345m (1,130 ft) were bored to 2.1 m (7 ft) diameter.

The constantly increasing acceptance of raise drilling is enhanced by development. A wider range of machines is available; machine drive system has improved, reliability has increased and cutter technology continues to rapidly improve.

The basic machine models are used for conventional raise boring - piloting down and reaming up, to drill:

- *Ventilation shafts,*
- *Water intake shafts and penstocks in hydroelectric power schemes,*
- *Ventilation shafts for road and railway tunnels,*
- *Rock passes for quarries,*
- *Emergency exits from tunnels and other underground spaces,*
- *Metro-escalator declines.*

To serve customer requirements, the Raiser Raise Borers have been tailored for specific applications, such as piloting up reaming down operation, downward box drilling with pre-drilled pilot hole and horizontal drilling of water supply and sewage tunnels.

Characteristics of Raiser Borers:

- *The rigid frame and base design give good stability to the derrick during reaming*
- *The electro-hydraulic drive system ensures smooth rotation with shock-free torque and thus gives exceptionally long operation time to both the raise borer and the drill string, reaming head and cutters*
- *Raise Borers are exactly machined to allow for a high-energy input and thus a high power/weight ratio. This means easy transport and handling, which is important especially in narrow mines and by helicopter transport in road less terrain.*
- *Pilot hole flushing medium is usually water, which can be re-circulated also air or foam can be used.*
- *The hydraulic drive and control systems ensure trouble-free operation in underground mines with sulphuric air or high iron dust level.*
- *The well-dimensioned components allow for long service intervals.*

The operating and drive systems are designed for normal maintenance and service to be administered by the drilling crew.

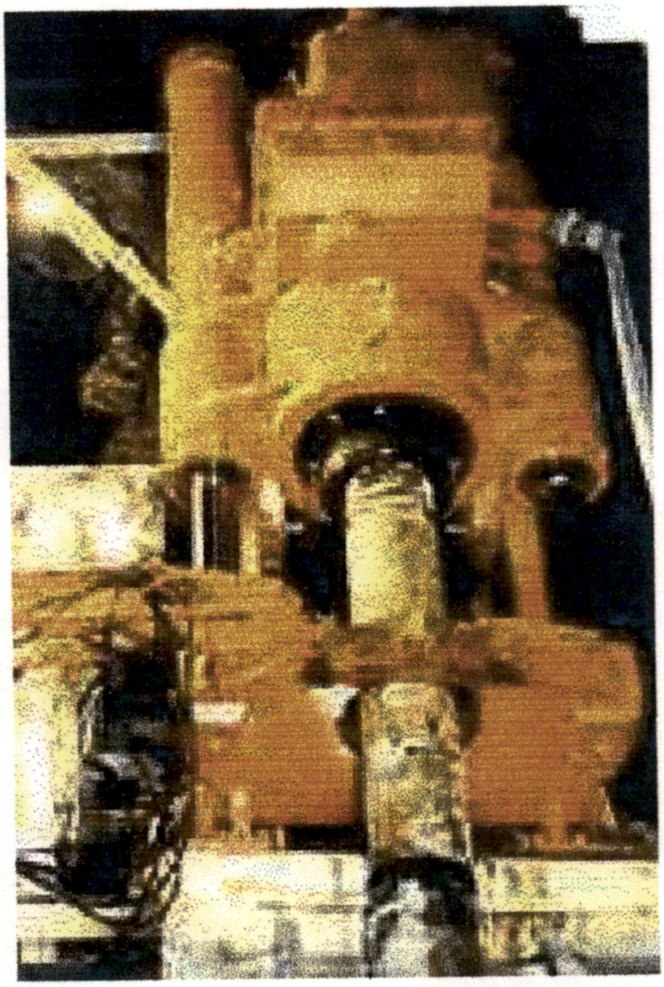


Fig.4.23 *Raiser 250-H drilling 4.07m/88m penstock at 45° angle for a hydroelectric power scheme.* (28)

Fig.4.24 *A Raiser 500-H drilling 3.05m /280m ventilation shaft.* (28)

Fig. 4.25 *Raiser 170-H drilling* ***1.5m / 160m water intake shaft 1400m over sea level.*** (28)

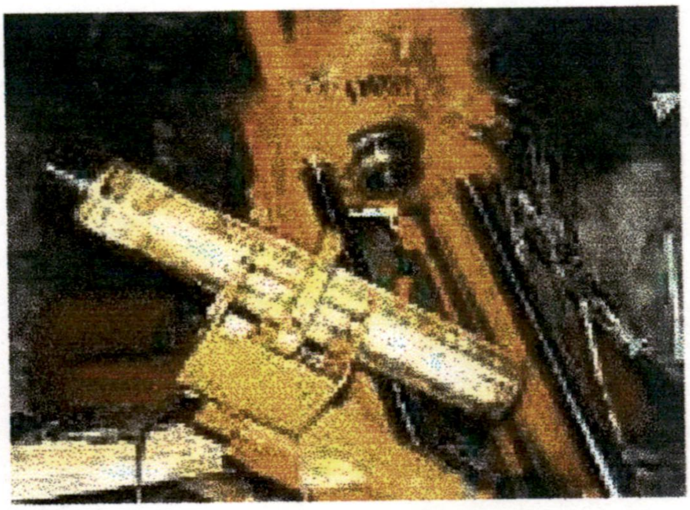


Fig.4.26 *Raiser 90-H drilling 2.1m/150m shaft.* (28)

4.4.1. *Standard Raise Drill.*

The consists of a drive motor and gear reducer to provided rotation and hydraulic cylinders for thrust. All the thrust and torque are transmitted through the drill string to the cutter head. The machine is set up at one level and a pilot hole is driven from that level-to-level below. Cutting debris from the pilot hole during the drilling operation is flushed from the hole by air or water and directed through the "blooie" assembly to a convenient point of discharge. After holing at the lower level the tricone pilot bit is removed from the drilling string and replaced with the reamer, which is then drawn back to the upper level. During the reaming operation, the broken rock falls as chipping to the lower level, where they are mechanically loaded.

4.4.2. *Standard Raise Climber*(31)

Originally developed for mining applications, the *Raise Climber* has gradually been improved to suit all kinds of raising in mines and underground civil engineering projects like shafts and penstocks for hydroelectric power plants, ventilation shafts for road tunnels etc.

The over 2300 *Raise Climbers* delivered so far have been used to drive more shafts and raises than any other system; in all kinds of rock, pilot and full-face, vertical and inclined, and even for raise and vein mining.

The Raise Climber Method consists of five steps, which make up a cycle: *Drilling, Loading, Blasting, Ventilation and Scaling* (show in Fig.5.16). The Raise Climber serves both as a work platform and as a means of transport to the work site.

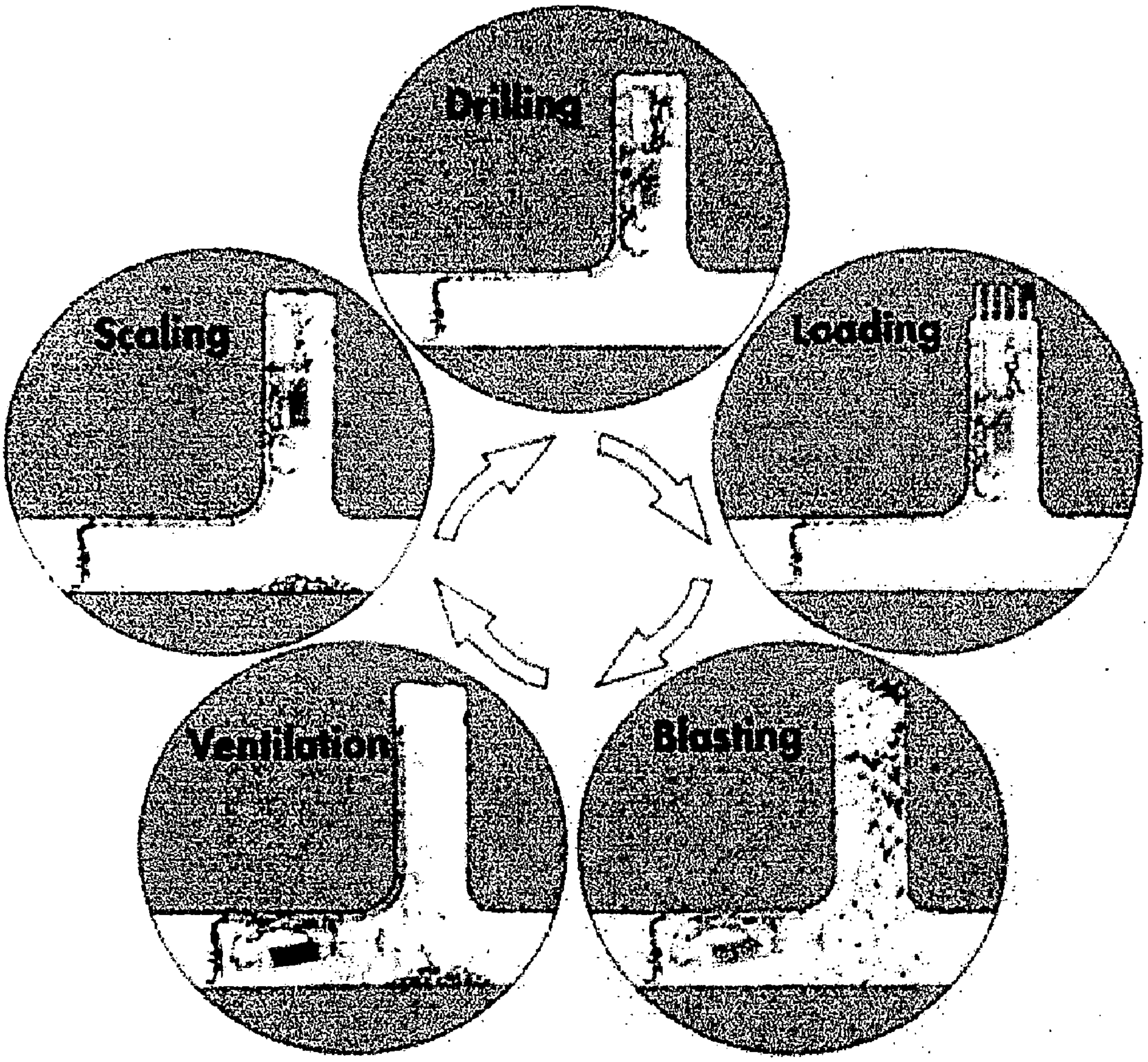


Fig.4.27 *Work cycle with Raise Climber.* (31)

It runs on a guide rail anchored to the hanging wall. Using curved guide rail sections, the direction of travel can be changed at any time; forward, backward or sideways. Raise Climbers are available with air, electric or diesel / hydraulic drive units. The longest shaft driven in one step so far is 1050 m (*Norway*). The platform can be any shape and size. The largest work platform supplied so far measured more than 30 sq.m.

4.4.3. *Pilot Hole Accuracy.*

The directional accuracy that is achieved with a raise-bored hole is not normally an important factor on alternatively short or small diameter rises. In the case, however, of very long raised or large diameter holes, which may be used for hoisting men or materials, the accuracy that can be achieved frequently become an important criterion in the evaluation of the application of raise boring, and definite improvements have to made in controlling deviation if this raising method is to be more extensively used.

At present it is not normally practical, economic or necessary to attempt to control the direction of the pilot hole by using directional drilling techniques. The employment of careful during procedures, as well as adequate stabilization in conjunction with some qualitative analysis of the relationship of the hole and the local geological conditions will normally result in an acceptable final hole location. This is particularly true in the case of raise-bored hole employed for purposes such as ventilation raises, one passes and so forth. When, however, it is necessary to satisfy more stringent accuracy requirements, the used of directional drilling technique may be considered. In general, these techniques are very expensive when employed in conjunction with raise boring. Two example of recent raise boring project where directional drilling techniques were made either available or used can be quoted.

(9)-p.4

As we did with the Tunnel Boring Machine, we will now seek to establish a cost per meter of advance and to do this we are assuming the raise drill will be written off over a period of 10 years on the basis of raised boring 1500 per year.

General speaking raise drills are purchased on the basis that the client will have at least 1000 meter of raised work during a year, and as to the life of a machine I can only point to the fact that the very raise drill we manufactured, some 25 years ago, is still at work.

In this study we are making a comparison between *raise drilling* and *raise climbing*, and at this stage it is worth making some general comparisons between the two systems, as follow:

Apart from raising by conventional means the alternative is the semi-mechanized method employing a raise Climber and having already established the ease of set up and operation of a raise borer, it may be useful to give a typical comparison.

A *raise climber* is a hoist unit with a working platform with rack and pinion drive, and a guide rail-a monorail with pin rack and integral pipes for air and water-which is secured to the wall of the raised by mean of bolts (*Fig.4.28*).

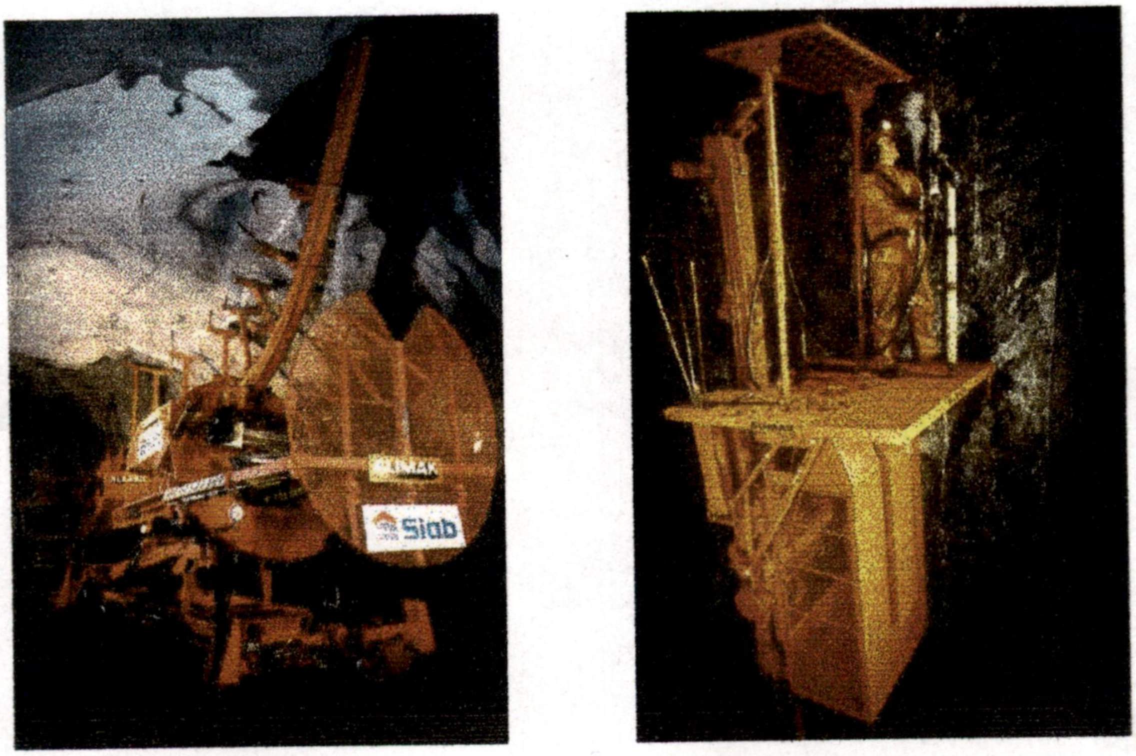


Fig.4.28 *Alimak Raise Clamber Machine.* (31)

A ventilation system has to be installed which will comprise two fans, one forcing and the other exhausting from the raise.

Drilling and charging operations are carried out from the platform with the miner working under a steel canopy. During blasting the raise climber must withdraw to the bottom of the raise to avoid damage.

After blasting the raise must be ventilated to clear exhaust gases, dust, fumes, and this is achieved by a water system built into the guide rails. It is also necessary to carry out scaling of the face and walls.

A typical cycle involves:

- *Travel to the top of raise (increase travel time on long raises)*
- *Install rail – one shift in every two,*
- *Drilling shot hole 30 – 35 holes say 1.5 m long,*
- *Transporting explosive to the face,*
- *Loading the round,*
- *Lower personnel and climber to bottom of raise,*
- *Blast,*
- *Ventilated raise,*
- *Travel to top of raise for scaling,*

In the course of a week, it is usual to allow two shifts to

- *Increase length of ventilation pipe – including defecting plates to avoid blast/sealing damage.*
- *Service the climber,*
- *Inspect guide and rail section.*

In general, terms a raise climbing operation would involve

- *4 personnel,*
- *Length of shot hole 1.5 m,*
- *Number of shot holes 30 – 35,*
- *Explosive 25 – 30 kg,*
- *Pulleys for each round 1.0 m – 1.2 m.*
- *Number of rounds per day ½*
- *Average monthly advance (basis three shift cycle) 30/60 m or 1 – 2 m/day.*

This monthly advance may be considered a good average as several sites achieve less than 30 m a month.

Contrast this to the continuous operation of a raise bore over says a 180 m raise (12/24 weeks by raise climber).

- *Pilot hotel operation at 2.5 m per hour = 72 hours.*
- *Ream 1.8 m diameter raise at 1.25 m per hour = 144 hours.*
- *Add for removing pilot hole bit and installing reamer plus time to remove reamer on completion = 24 hours.*
- *Total 240 hours – 3 shifts per day of 6 hours (working) = 40 shift = 2 weeks.*

Above assumes set up and break down of machine and equipment plus providing a service is similar.

Apart from the considerable saving in time and labor the operative's work in complete safety – no one enters the raise and no explosives are used.

The smooth bore hole gives greatly improved flow characteristics as compared to the rough blasted raise and means in effect a smaller diameter raise bored hole for a given flow.

Let us look at the cost base on *price in Rupees in 1983*, which have been increasing by 360 % to take into account the cost of inflation. Interest 7 % compounded annually, yielding $(1+0.07)^{19}$ equal to 3.6 times increased. (9)-p.6

A. RAISE BORER	*Rs./meter raise*
A typical Raise Boring Machine complete with all drill pipe and reamer for 200 meter of raising would cost Rs.430 lakhs, plus 65 % Import Duty = Rs.709.5 lakhs. *Owning costs on basis write off over period 10 years, at 1500 meter a year (15000 meters).*	*4730*
Interest based on RBM financed by 5 year EXIM loan at 9 %, plus fees.	*1022*
Interest on Import Duty and 15 % down payment, based on 18 % Interst	*1725*
Cutter cost – vary dependent on strata. Assume strata 50/200 MPa with low quartz content.	*2880*
Reamer costs.	*144*
Maintenance 20 % of cutter costs.	*576*
Insurance spares 10 % of original RBM value.	*288*
	11365

B. ALTERNATIVE RAISING BY RAISE CLIMBER	*Rs./meter raise*
Original cost approximately Rs.90 lakhs, plus 65 % Import duty = Rs.148.5 lakhs. *Owning costs based on 7 year life at 350 meters a year (2450 meters).*	*6062*
Interest at 18 % per annum over 5 years, *In view of the lower cost of a raise climber, it is unlikely that medium term financing would be available, and have, therefore, assumed commercial rates of interest. Equally to get a similar comparison have, in both cases, only assumed interest payments over 5 years.*	*3010*

Steels and Explosives *Basis 35 holes 1.8 meters long for a 1.4 meter pull = 63 meters.* *Assume life of steels 200 meters and cost Rs.3240 each = Rs.1020.* *25/30 kilos of explosive at Rs.54 a kilo = Rs.1485* *Total Rs.2505 for a 1.40-meter pull, equivalent to Rs.1790 per meter.*	*1790*
▪ *Maintenance, including ventilation, scaling, etc (20 % of excavation cost)*	*358*
▪ *Insurance spares 10 % of original value*	*358*
Sub total	
You will appreciate from the previous information that one would expect to have at least two extra men involved on a raise climbing operation at, say Rs.200 a day	*400*
TOTAL	**11978**

4.4.4. Conclusion the use of Raise Boring machine

In conclusion, the use of mechanical boring equipment for the *drilling of raises* and *shaft* will continue to expand. The shafts will grow in size as cutter costs are reduced through continued research. In some cases, new high speed drilling system for development or for the speedy increase of ventilation capacity will be important factors contributing to profitability.

The advent of more stringent safety regulations will also be an important factor; even through possibly mechanized equipment would not be used purely on economic grounds. The possibilities of new systems and new design must continually be re-assessed since many of the factors which determined feasibility in the past, such as *bore diameter* and *depth capability, cutter costs* and *penetration rates,* are changing rapidly.

Chapter 5
COMPARISON OF CONVENTIONAL AND MODERN TUNNELING

5.1. COMPARISON CRITERIA

The basis of comparison between conventional and modern tunneling has been grouped under following broad categories:

1. *Speed,*
2. *Cost,* and
3. *Safety*

These are discussed below separately.

5.2. COMPARISON OF TUNNELING SPEEDS.

The two methods of tunneling have had their spells of good and bad times of progress depending upon the strata encountered. In the conventional method, average progress of *4.5 m' per day* for heading and *13.5 m' per day* for benching are obtained in *Indian conditions,* which does not seem to have been attained consistently in any of the projects executed or under execution. Table 5.1 shows the average progress rates obtained on various tunnels in *Northern India.* It also shows expected average progress if moles could have been used on these tunneling works.

The information given in the table for average sustained progress with conventional method is based on project report; lecture write-ups, books and paper or discussions held with construction engineers of the various projects. The expected average progress of mole has been computed based on data available for projects in foreign countries where moles have been used, the soil conditions and tunnel diameter being equivalent.

For *Natpha-Jhakri* project construction had been planned, through *seven adits* provided/available along the tunnel alignment and has been facilitated by construction from *nine headings* simultaneously at

Table: 5.1 *Advance Rates on some Tunneling Projects in North India.* (20)-p.56

Name of Project	Diameter (ft.)	Length (ft.)	Geology	Average sustained progress with conventional method per heading (ft./day)	Expected average progress with Mole in similar type of rocks (ft./day)
1. BSL Project :					
a. Pandoh-Baggi Tunnel	25	43,200	Phyllites, Quartzites & granites	7.25	80
b. Sundernagar Sutlej Tunnel	28	40,100	Conglome-rate, dolomite limestone & quartzites	8	80
2. Pond Dam Diversion Tunnels	30	15,662	Sandstone & claystone	3.7 to 4.5 for T1 & T2	120
3. Yamuna project stage-II :					
a. Part-I	23	20,300	Quartzitic slates	8	100
b. Part-II	24.6	19,350	Quartzitic slates, Nahan sandstone and claystone	8	100
4. Ramganga Project :					
Diversion tunnels (2 nos)	31	4,155	Sandstone and clays shale bands	Approx 5	120
5. Nathpa-Jhakri Tunnel	36	89,567	Quartzite, gneiss-schist and gneiss's	14	120

different places [(3)-p.ix-4]. Total time to complete this project with conventional method is 4 years [(3)], versus a Tunnel Boring Machine at *36.5 m/day* or *120 ft./day, with 80% availability* is around 2.5 years, so giving a *saving in time of 1.5 years.*

5.3. COMPARISON OF COST UNDER INDIAN CONDITION.

For cost comparison, case of *Nathpa-Jhakri* project involving a tunnel of 10.15 m (33' 4") finished diameter, has been considered. The tunnel has been bored in *medium to hard rock* of compressive strength from 20,000 to 40,000 psi (1400–2800 kg/cm^2) in the Himalayas geology. The total length of the tunnel is taken as 27.3 km. The method of tunnel construction as adopted in this project is given as *appendix-I.* The break-up of costs for the two methods of tunneling is given as below:

5.3.1 Cost with Conventional Method.

Excavated diameter = 11.15 m (*assume 50 cm Concrete lining*)

Volume excavated per meter length $= \frac{\pi}{4} \times 11.15^2 \times 1$

$= 97.64$ m^3

Assuming over-break of 12.5 %, volume excavated = *110* m^3/m'.

Volume excavated per foot length = 36 ft. 8 in (*assume 1' 8" Concrete lining*)

$$= \frac{\pi}{4} \times \frac{36.67^2}{27} \times 1$$

= *39.11* cyd

Assuming over-break of 12.5 %, volume excavated = 44.00 cyd/ft.

The abstract of cost given in *appendix- **II*** is based on the rates provided in *Nathpa-Jhakri modified report* (1986), which have been increased by 300 % to take into account the cost of inflation. Interest 7 % compounded annually, yielding $(1+0.07)^{16}$ equal to 3 times increase.

Average cost of excavation in HRT/cu.m:

$$\frac{(73.33 \times 2280 + 36.67 \times 1380)}{110} = 1983 \quad \text{Rs./cu.m}$$

∴ *Hence, cost of tunnel per meter length* = Rs.1983 /m^3 × 110 m^3/m'
= ***Rs.2,18,130 / m'***

Total cost of conventional tunneling for *Natpha-Jhakri Head Race Tunnel* (27.3 km) = *Rs.2,18,130/m'*×27,300 m = ***Rs.595.5** crores.*

5.3.2 Cost with Tunneling Machines.

Since the cost depend upon advance rates, different advance rates have been assumed to compute the machine cost and horsepower required to drive the respective machines. These are given in *table: 5.2. Original Cost of Tunneling Boring Machine* (below).

Advance rate *(ft./hr)*	Cost of Machine	Horsepower required
50 (15.24m/hr)	Rs.8400 *lakhs*	5400 hp
12.5 (3.81m/hr)	Rs.2887.5 *lakhs*	1350 hp
5 (1.52m/hr)	Rs.1312.5 *lakhs*	540 hp
1 (0.30m/hr)	Rs.1050 *lakhs*	108 hp

This information has been used to compute underground equipment cost and power cost in Detail Tunnel-Cost of Estimate Tunneling Boring Machine. *(Appendix-II).*

The results are summarized below in *table: 5.3*

No.	*Item of Cost*	*Cost in Rupees / cu.m at advance rate of*			
		15.24 *m./hr*	3.81 *m./hr*	1.524 *m./hr*	0.305 *m./hr*
1.	Labor	3.89	15.56	38.91	194.55
2.	Underground equipment.	561.70	220.48	122.99	106.74
3.	Cutters	277.21	277.21	277.21	277.21
4.	Other expendable materials	760.92	760.92	760.92	760.92
5.	Power	12.46	20.80	37.48	148.71
6.	Miscellaneous items	642.36	642.36	642.36	642.36
7.	Insurance Spare (20% of original TBM)	63.03	21.67	9.85	7.88
8.	Depreciation of machines	12.68	1.09	0.20	0.03
	Sub - total	2334.25	1960.09	1889.91	2138.40
	Add for construction and maintenance of haul road at 4 % of total charges.	93.37	78.40	75.60	85.54
	Add for electric energy charges at 2 % of total charges	46.68	39.20	37.80	42.77
	Prime cost	2474.30	2077.69	2003.31	2266.70
	Add overhead charges and contractor's profit at 20 % of prime cost.	494.86	415.54	400.66	453.34
	Total	**2969.16**	**2493.23**	2403.97	**2720.04**

Table: 5.4 Comparisons Costs of Excavation Tunnel.

No.	*Method*	*Cost of excavation tunnel per cu.m (Rs.)*	*Cost of excavation tunnel per meter length (Rs.)*
1.	Conventional (*overbreak 12.5 %)*	**Rs.1983** /m^3	Rs.1983 × 110 m^3 = Rs.2,18,130 /m'
2.	Tunnel Boring Machine minimum obtained. (*overbreak 2.5 %*)	Rs.**2403.97**/m^3	Rs.2403.97 × 100m^3 = Rs.2,40,397/m'
Saving cost of excavation tunnel by Conventional method (Drilling & Blasting)		*Rs.22,267/m'*	

5.3.3. Result of Comparison.

The costs of conventional and tunnel boring machine methods for 11.15 m (36 ft. 8 in) excavated diameter tunnel in medium hard rock under Indian condition as obtained from the above analysis show the following comparison. Thus, it is found that for 27.3 km long tunnel, the saving in cost for excavation through use of Conventional method (*Drilling & Blasting*) could be as much as ***Rs.60.78 crores,*** *@ Rs.22,267/m'* for *27,300 m* length of tunnel. Therefore, that gets saving for excavation by conventional method is around ***9.25 %*** than Tunnel Boring Machine (TBM).

5.3.4. Break-up of Comparison with Concreting.

Table: 5.5 Comparisons Costs of Excavation with Concreting Tunnel.

No.	Description	Volume (m^3)	Rate (Rs/cu.m)	Rs./m' of advance	Total Cost (Rs. Lakhs)
A.	Conventional Method				
1.	Total Excavation per meter advance 11.15 m diameter, plus 12.5 % over break.	110.00	1,983.00	218,130.00	59,549.49
2.	Concreting over break portion $= 110 - (\pi/4 \times 11.15^2)$	12.357	1,700.00	21,007.47	5,735.04
	(Lean concrete excluding concrete lining)		Rs.	**239,137.47**	**65,284.53**
B.	Tunnel Boring Machine				
1.	TBM total excavation 11.15dia. Plus 2.5 % over break = 100 m^3	100.00	2,403.97	240,397.17	65,628.43
2.	Concreting over break portion $= 100 - (\pi/4 \times 11.15^2)$	2.357	1,700.00	4,007.47	1,094.04
	(Lean concrete excluding concrete lining)		Rs.	**244,404.64**	**66,722.47**
C.	Comparison (saving cost of Conventional method)		Rs.	**5,267.17**	Rs. **14.379** *Crores*

Thus, for 27.3 km long tunnel, the saving of cost for excavation through use of Conventional (*Drilling & Blasting*) method include concreting *(without concrete lining)* could be as much as ***Rs.14.38crores***, @ *Rs.5,267/m'* for *27,300 m* length of tunnel, which is still more economize around ***2.2 %*** than Tunnel Boring Machine (TBM).

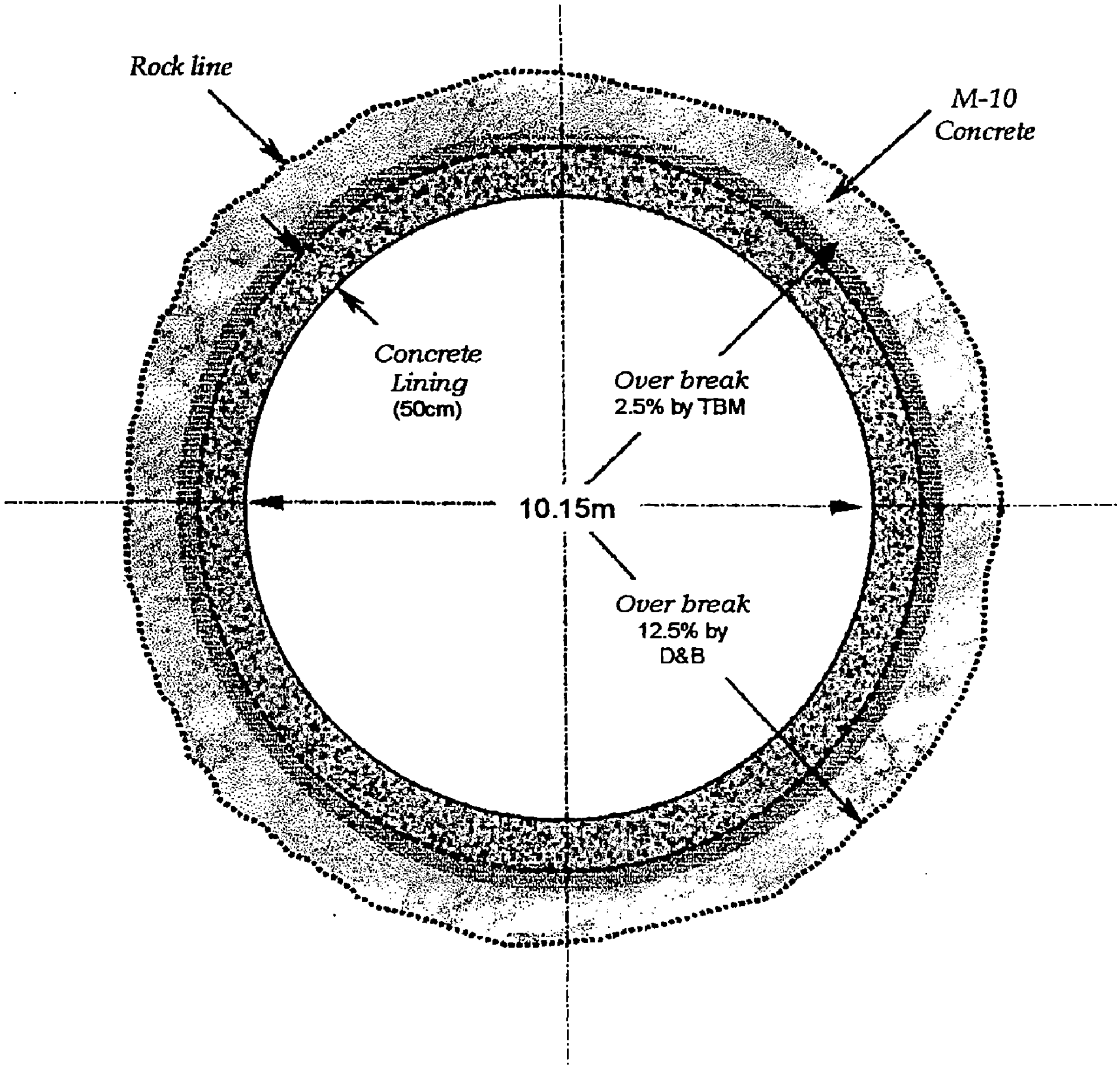


Fig.5.1 Comparison of section for concreting

5.4. SAFETY

In all tunneling work, natural hazards are bound to take place, but there is always a tendency to under estimate the problems of falling rock in such construction. This is particularly true of large diameter tunnels in comparatively good rock where supports are not required. With machine bored tunnel, simple and rapid support systems, such as robolt, wire net etc. can be emplaced continuously at the heading while the machine advances, thus obviating the danger from rock falls.

In addition, since no blasting is required, the hazards associated with the handling of explosives are eliminated. The Tunnel Boring Machines can be equipped with detection systems for methane and other gases, thereby reducing the danger due to their explosion.

Several fatal and other accidents have occurred during conventional tunneling operations in all countries. Some of the major accidents that occurred in India are citied below:

- ✓ During the construction of *Sundernagar-Sutlej* Tunnel from *Harabagh* adit a huge cavity formed submerging both men and material under the muck.
- ✓ In *Pandoh-Baggi* an accident due to mishandling of explosives took lives of some workers including a foreman.
- ✓ Twice very serious accidents due to fire took place in the diversion tunnels at *Pong Dam, Talwara.* Once shuttering and wooden blocking caught fire due to careless welding of reinforcement, and three workmen were suffocated to death. On the second occasion, one workman died as fire broke cut near junction of intake tower and tunnel.
- ✓ As against such accidents in conventional tunneling no serious accidents have been reported on machine tunneled projects. For example, there was no fatal accident on 8.6 mile long *Blanco tunnel* under the *Continental Drive in USA*, bore with TBM (moles). With over a million man-hours of exposure, only *six* minor lost-time

accidents occurred on this tunnel. The most serious injury occurred during the tunnel excavation when a slab of rock slid from the tunnel wall striking a workman and fracturing his leg.

The frequency of accidents with machine tunneling has been about 1/3 rd of that with conventional methods and the accidents have not been severe.

Since the experienced workmen for such arduous work as tunneling are difficult to find, their loss due to accidents would be irreparable. With every fatal accident, years of experience are lost and they lower the morale of other workmen in addition to the loss of many man-hours of the labor due to dislocation of normal work caused by these accidents. (20)

Chapter 6

TUNNELING PROBLEMS IN HIMALAYAS

6.1. GENERAL TUNNELING PROBLEMS.

The tunneling problems in Himalayas region generally due to the complex geological condition *unpredictable*, it is seen that are large variations between pre-construction geological reports in most cases. Such a situation arises because of insufficient study of the behavior of rock mass through which tunneling is to be done.

The behavior of the rock mass tunneled through is important in determining the stability of tunnel opening during and after construction. Advance knowledge of the behavior of the rock mass is very difficult to obtain and it is rather impossible to have the prior knowledge of a specific problem reach. The pre-construction geological investigation gives some prior knowledge of geological problem.

6.1.1. Problem due to Squeezing and Swelling Rock Condition

Among the most feared hazards in tunneling operations are altered and or fragmented rock masses that squeeze and swell. Pressures generated by such materials are capable of causing failure of heavy supports, and containing may be a major problem.

The squeezing and swelling rock conditions were first encountered in the *Alpine tunnel.* In the Himalayas formations squeezing ground conditions had been encountered in major portion of the *Chibro-Khodri, Giri-Bata,* and *Loktak* tunnels, short reaches were encountered in *Pandoh Baggi,* and *Maneri - Bhali* tunnels. Squeezing ground condition created problems of tunnel instability and affected the tunnel progress largely. Excavated the cross section got reduced in dimensions due to tunnel closure and the supports got buckled and twisted very badly.

Squeezing rock is *a weak plastic rock that moves into the tunnel opening because of the weight of overburden rock mass over the tunnel opening.*

Swelling rock *is the rock that is forced into the tunnel opening because of the increase in volume due to absorption of water by the rock mass.* (10)-p.120

Both the *squeezing* and the *swelling* phenomena exert heavy pressure on the supporting system causing distortion and twisting problem in tunneling operations.

6.1.2. Problem due to Ingress of Water

Ingress of water causes serious problems in tunneling operations. This problem arises when the tunnel grade is passing below the water table of the ground or when the rock mass around the tunnel opening is charged with water from an underground reservoir and lying under heavy overburden pressure.

Problem in tunneling due to the heavy ingress of water flooded the tunnel. This stopped all construction work. No amount of shotcreting the rock face to form a bulkhead could prevent the flow of water.

The solution adopted to reduce the hydrostatic pressure of the water, among others drilled hole 5 m length drainage.

Grouting has also done to control the inflow of water to permissible limit. These two arrangements were sufficient to control the excess discharge.

6.1.3. Problem due to Thrust Zone

Presence of thrust zone across the tunnel alignment causes sliding of the rock mass even with a low order of tectonic force, which creates problems of stability of the tunnel. Apart from this, the rock mass in this zone is of poor quality, which causes unexpected problems in tunneling operation. It is also observed in a few cases that the tunnel wall displacement in this zone is usually very severe. Due to the above behavior of the thrust zone, it is highly essential to avoid such zone while the tunnel alignment.

Tunneling through the thrust zone not only takes a larger time but also involves more money (*due to heavy steel support and flexible lining arrangement*). At site where the thrust zone cannot be avoided the tunnel is to be aligned in such a way that it passes normal to the thrust zone to keep the magnitude of problem to a minimum. It is observed from the geology of the Himalayas that two main boundary faults run from Jammu & Kashmir to Assam along its foothill. These are low angle reverse faults called locally by various name.

6.1.4. Problem due to Presence of Gas

Gases are sometimes encountered during tunneling, they lead to the following:

a. *Problems in tunneling due to poisonous gases,*
b. *Problems in tunneling due to explosive gases,*

The tunneling problem due to poisonous gases is further classified as:

1. *Naturally occurring poisonous gases,*
2. *Formation of poisonous gases due to use of mechanical equipment in tunneling operations.*

The poisonous gases cause irritation, suffocation and sometimes prove fatal to workmen inside the tunnel. The irritation and suffocation arises when the concentration of the poisonous gas such as *methane* (CH_4) is also called *'marsh gas'*, *carbon monoxide* (CO), *carbon dioxide* (CO_2), *oxides of nitrogen,* etc. are more while inhaling and a man dies with higher concentration of the above gases.

Methane is most abundant in the vicinity of coal and petroleum deposits, but exists also in considerable quantities in other sedimentary environments, where it has formed by slow decay of bituminous material of organic origin. (10)-p.132

The naturally occurring poisonous gases are formed due to presence of coal or other organic material within the rock mass. Generally, coal or other organic material under goes chemical reaction under high pressure and temperature liberating methane and other poisonous gases. These gases migrate to the tunnel through the fissures, joint, etc. and pollute the air inside the tunnel. When the inflow of such poisonous gas is high, it leads to problems in tunneling operation, and consumes more time for its dilution to a permissible limit. Accordingly, the cycle time of tunneling operations increases.

Solution to gaseous problems due to presence of Methane and other poisonous gas do not pose much discomfort in tunneling operation, as they can be solved by two ways.

(i). *Prevention of gas layering,*

(ii). *Changing of tunnel alignment*

As per Indian Standard Code IS 4756 – 1968 permissible percentages of pollutants in air are as follows: (*Table: 6.1*)

Gas	***Percentage by volume:***
Oxygen (O_2)	19.50
Methane (CH_4)	0.50
Carbon monoxide (CO)	0.01
Carbon dioxide (CO_2)	0.50
Hydrogen sulphide (H_2S)	0.001
Aldehyde	0.001

Dust particle of size 0.5 – 5 μ 450 particles /cc

If the concentration of the poisonous gas is beyond the permissible proportions given by Indian Standard then the preventive measures are adopted. The prevention of poisonous and explosive gas layering is done by the following methods:

a. *Reduction or regulation of gas emission,*
b. *Prevention of gas by providing Hurdles or Baffles,*
c. *Prevention of gas by using compressed air,*
d. *Prevention of gas by using vortex generator.*

6.1.5. Problem due to High Rock Temperature.

High rock temperature creates serious problem on smooth tunneling operations. From the experience, it is observed that for every 100 m rise in the overburden above the tunnel grade there is a rise of 1°C in temperature. This problem arises where there is overburden, and such problem was encountered in *Nathpa-Jhakri* Head Race Tunnel.

After tunneling for about 1.5 km from the intake face, very high temperature to the order of 40°C was observed inside the tunnel. The high temperature inside the tunnel caused exhaustion amongst the workman and they could not work efficiency for the whole shift. Due to this, the progress of tunnel work was reduced.

The solution for high temperature, in the ventilation arrangement consist of a light *venturi pipe* made of aluminum with 250 mm inlet diameter, 75 mm diameter at venturi thrust 200mm outlet diameter and 1200 mm in length weighing roughly 20 kg located at the crown of the tunnel. At the outlet end, this pipe is connected to a 200 m dia. air duct with its far end just behind the working face.

6.2. *PROBLEMS WITH TUNNELING MACHINE*

The tunneling problems used the Tunnel Boring Machine as far as which are enumerated below:

a. *The cutters and cutter-head problem,*

b. *Problem of Hard Rocks,*

c. *Gas Problem,*

d. *Muck handling Problems,*

e. *Tunnel Support Problem,*

f. *Alignment Control Problem,*

6.2.1. *Cutters and cutter-head problem*

Tunneling machines are manufactured to order and are custom tailored for specific requirements. When a particular tunnel has been bored, the machine may not have used its full life. Its is *usually difficult to find another tunnel of some diameter to be bored in almost similar geologic conditions.* However, developments have taken place in this field and adjustable cutter-heads are being provided on the machines by most of the mole manufacturers. This adjustability is also required when dissimilar ground conditions are encountered in the same tunnel to provided more space for lining in weaker rock portions. So far, an adjustment of about 1 m (3 ft) in diameter is possible.

In certain cases, the modifications on the mole may make it usable on another project. An example in *Mangla Dam in West Pakistan* mole has been used on *Mersey Kingway* tunnel construction in England. The cutter-head, besides being reduced in diameter from 11.125 m (*36 ft. 8 in.*) to 10.33 m (*33 ft. 11 in.)* was to have a 1.67 m (5 ft. 6 in.) diameter snout giving access to the pilot tunnel. Alterations to the main assembly included modifications of the propulsion system and the provision of equipment for segment handling and erection.

The most significant cost item in machine tunneling of hard rocks is expected to be the cutter costs. Hence, a lot of research and development is required in this field.

6.2.2. Problem of Hard Rocks.

The mole yet to breaks the hard rock barrier. Before discussing this aspect, it would be worthwhile examining the different rock strength as under:

- Rock compressive strength up to 10,000 psi is soft,
- From 10,000 to 20,000 psi moderately hard,
- From 20,000 to 30,000 psi Medium hard,
- From 30,000 to 40,000 psi Hard,
- From 40,000 to 50,000 psi Very hard,
- Over 50,000 psi extremely hard,

In addition, Moh's hardness scale rates rocks and minerals for resistance to abrasion in the following ten categories in order of increased hardness.

Table: 6.2 (13)-p.125

Scale No.	**Rock**	**Scale No.**	**Rock**
1	Talc	6	Feldspar
2	Gypsum	7	Quartz
3	Calcite	8	Topaz
4	Fluorite	9	Corundum
5	Apatite	10	Diamond

Common rocks encountered in construction have Moh's ratings approximately as follows: *Table. 6.3*

Shale	Generally less than 3
Sandstone	Between 3 and 7 depending upon cementing agency
Limestone	3
Marble	3
Slate	4 to 5
Granite	6 to 7
Schist	6 to 7
Gneiss	6 to 7
Quartzite	7

Generally in *Himalayas,* tunnel is underlain by *quartzite, gneissose-schist and gneisses,* which are intruded by *amphibolites, granite* and *pegmatite,* rock compressive strength up to 2800 kg/cm^2 or 40,000-psi (hard rock classification). The last experienced in *Dorchester tunnel USA,* rock of 3870 kg/cm^2 (55,000-psi) strength comprising of argillite and in *Cookhouse tunnel South Africa* rocks up to 4200 kg/cm^2 (60,000-psi) *comprising of sandstone, siltstone and mudstone* have been successfully bored by *Ingersoll-Rand Rock tunnellers.* These hardest rocks were encountered only in small stretches, so they did not materially affect the cost and advance rates. The cost is one factor, which will govern the use of these tunneling machines in the hard rock range.

In addition, for *Himalayas* tunnel project the reduction of tunnel costs will come not only from even more powerful machine, but also from a better knowledge and research into:

a. *Approximate carbide selection for cutters,*

b. *Better cutter shapes, and*

c. *Better reclamation (i.e. re-tipping and grinding) of cutter teeth.*

6.2.3. *Gas Problem.*

The presence of corrosive, toxic and explosive gases can be expected in many tunnels in sedimentary rocks. These can not always be detected by core drilling. Previous experience in underground works under geologically similar condition is, today, the best indicator of such hazardous. If the slightest doubt exists about the presence of these gases, the boring machine must be provisioned to face them with complete safety to machine personnel.

Unlike other tunnel boring machine, the Ingersoll-Rand tunneler employs a unique *"pilot-pull principle"*. A central pilot cutter precedes the full diameter cutter-head, continuously sampling the ground ahead of the face while boring, giving *advance warning* of any *gas, water or ground problems* that lie ahead, and even a trace of the highly inflammable gas is sufficient to shut down the power and alert the crews.

6.2.4. *Muck handling Problems.*

Machine tunneling is a production operation. Like any other production line, it must keep moving to achieve the optimum economic advantage of the both men and machinery. This production line is made up of three elements. The first is a *tunneling machine*, the second is *muck removal* system and third and the most *unreliable is geology*. With suitable tunneling machine design, the highest advance rates could be expected. However, the mock disposal system must be able to keep up with these fast advance rates.

The muck removal systems used so far have been loco trains, conveyors, slurry pipelines, pneumatic conveyors etc. Whereas the most commonly used system for a long haul has been mine cars hauled by electric or diesel locos, short tunnels have used conveyors meet the continuous operation requirement of this production system, would be belt conveyors extending from the tunnel heading to the portal. However, this being too costly is ruled out at present. However, as faster advance rates are attained and no corresponding cheaper muck handling system is devised, the belt conveyor may become the best choice.

6.2.5. Tunnel Support Problem.

Some type of support is required in most of the tunnels to prevent falling in of rock. To support stratified and crushed rock or rock slabs and to contain rock bursts resulting from stress relieving in the rock surrounding the tunnel periphery. Various support systems relevant to the type of strata to be supported have been devised and almost mastered and this is one field, which has kept apace with the advancements in tunneling machines. Hence, the problems relating to support systems have almost been solved. However, the various types of support systems in use with the tunneling machine at present are given below:

6.2.5.1. *Use of the beams.*

This is a common support system in which wide flange steel beams bolted at top and spaced 60 – 180 cm (2 to 6 ft) or more apart, are provided. The sizes of beam depend upon the loads encountered. Special jigs are provided on the mole to rapidly fix the segments of ring beams in position a conveyor along the top of the mole frame carries these ring beams from the tail of the mole to the erector in the front. These may be carried inside the tunnel on the returning empty mine cars or special mining cars.

6.2.5.2. *Use of the Rock Bolts.*

These are being increasing used in recent years due to lower cost and rapid installation. These usually consist of steel-rods ¾ to 1½ in. diameter and about 1.5 m (5 ft) long.

The size and length will, in fact be governed by the specific needs. Drilling machines are mounted on the mole and these drill the holes while the cutter-head is in operation. The number of these machines is so adjusted that the requisite number of hole around the tunnel roof are drilled before the shoving of machine is done for the next cycle. Fixtures are also fitted on the machine to install the rock bolts rapidly.

6.2.5.3. *Use of Gunite or Shotcrete*

This is also a popular method to protect rock against loss in strength due to exposure and to provided tunnel support along with wire net and roof bolt. This method was developed in *Nathpa-Jhakri* tunnel and is known as the Austrian method. Shotcrete has been used to build up two or more layers of lining, each with wire mesh reinforcing to provide the entire lining support required

6.2.6. Alignment Control Problem

Both grade and alignment can be controlled within inches by the use of *Laser.* Whether we have to move straight or along a radius, the requisite accuracy is obtainable. The lasers are now almost universally mounted on the tunneling machines. A brief description of how a laser works is given below.

Laser (*L*ight *A*mplification by *S*timulated *E*mission of *R*adiation) action occurs when atoms is certain materials are excited externally by intense light or high voltage as in the gas laser. Electrons in the atoms are raised to higher than normal energy levels, become unstable and begin returning to their lowest energy levels. As this happens, each electron gives off a basic unit of light a photon. The mirrors at each end of the tube, one only partial silvered, move the photons back and forth, which stimulates other excited electrons and caused them to give off light. This cascading action ultimately results in a unidirectional beam of coherent laser light that emerges through the imperfect mirror. Unlike ordinary incandescent light, which is a blend of many wavelengths, traveling in every direction, laser waves is coherent, all of one wavelength. Laser light waves are all in phase and moving in the same direction, thus giving a straight and narrow beam.

The typical laser designed for construction has an output of 0.002 watt. It is usually a gas laser, and produces an invisible (in day light) red beam about ⅛ in. diameter. When interrupted, say with a sheet of paper, the beam produced a ⅛ in diameter dot of light at 7.5 m (25 ft) and 150 m (500 ft) the dot is nearly the same size because laser light is coherent or monochromatic (of one wave length). Its operating range is about 900 m (3000 ft) The unit weighs between 7 – 10 kg (15 - 20 lbs) and is power by either 110 volt AC or an automobile battery. If may cost between $ 2,000 and $ 4,000.

Laser guidance could be maintains precise line and grade. The Tunnel Boring Machine enables to respond to a precision laser guidance system with unusual speed and accuracy. This assures that line and grade will be accurately maintained.

The laser beam have to periodically moved forward in the tunnel and aligned by the surveyors. The beam is reflected off a mirror mounted on back of the gearbox to the target located on the thrust ring. The method in which steering correction are made is show on *Fig.6.1* (Laser Guidance.) (12)

In *"Condition I"* in which the tunneler is on the correct course, laser beam "A" strike mirror "B" and reflectects back to center of target "C".

In *"Condition II"*, the tunneler is not on the correct course and reflected laser beam (broken line) is off target. A horizontal steering correction changes the angle of mirror "B" by the same angle, which throws the laser beam back on target "C". The machine is now aimed in the right direction to return to and maintain correct course as long as the reflected laser beam is kept on target.

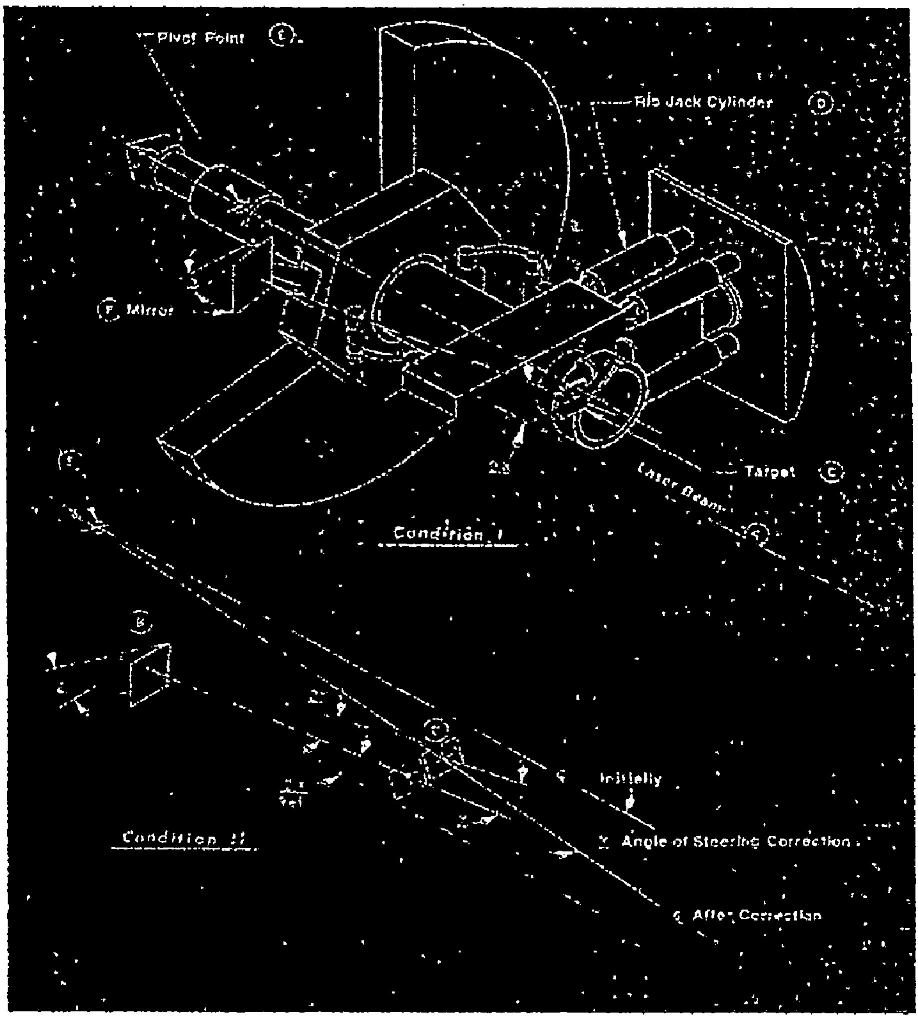


Fig.6.1 Laser Guidance.

6.3. *OTHER MISCELLANEOUS PROBLEM.*

These may include sufficient access facilities to the tunnel project area, as the largest single component that can be conveniently transported will govern the road width and bridge design. In addition, there should be sufficient assembly area and crane facility available at the tunnel portal. The electric power should be made available according to requirements. The assembly of machine in many cases; especially in urban areas has been done by constructing a shaft and then driving some length of the tunnel by conventional methods to make space for assembly of mole.

The tunneling machine *are not being manufactured* in India and will *have to be imported,* hence the *foreign exchange element* in their use would be *almost 100 %.* The present cost of these machines varies between US$ 600,000 and US$ 5,000,000 in the manufacturing country depending upon the diameter. Therefore, the *minimal cost* of tunneling machine when it arrives at the project site in India would be around *Rs.15 crores.* Not only that, the *spare part* will also *have to be imported combating the downtime of machine.* This would involve additional foreign exchange and time in the transport of the spare parts from overseas and will be a great bottleneck in the use of moles.

In additional to this, the technical know-how for operating and maintenance of the machine will have to imported till such time as the local labor are sufficiently trained to operate these sophisticated machines.

One fear, may be sometimes expressed is that the workers would be rendered jobless, if such automatic machine are used for construction. For example, there are about 2000 workers engaged on tunnel excavation alone on the *Nathpa-Jhakri in Beas Sutlej Link Project.* These workers would have put in about 2.92 million man-days in 4 years. If completing the project 1.5 year ahead of schedule would have provided 165 MW of electric power from *Dehar*, which could gainfully employ industrial workers. One MW of load on an average would provide jobs to about 50 workers. Therefore, 4.5 million man-days would have been utilized which is 3 times the man days lost due to delayed construction. Thus, the use of moles would indirectly increase the employment opportunities substantially and the fear factor of rendering workers *jobless* appears unfounded. (20)

Chapter 7

CONCLUSIONS

Based on analysis done in this study and described in previous chapters for conventional and modern tunneling work, following conclusions relating to various aspects of Conventional and Modern Tunneling Technique with Reference to Himalayas, are as follows:

1. By conventional tunneling methods, a tunnel of any shape can be constructed in varying site conditions. On the other hand, Tunnel Boring Machine can be used only for circular shape in rocks unless shield TBM is used.

2. Excavation speed by TBM is around 36.5 m/day (120 ft/day), versus *4.5 m/day for heading* and *13.5 m/day for benching* by conventional method using *modern tunneling equipment.*

3. Excavation by conventional method may yield an over break of about 12.5 % to 15 %, but excavation by TBM yields an over break of much lower order about 2.5 %, since no blasting is required.

4. Tunnel Boring Machine operation needs fewer personnel, but they have to be skilled, because it consists of self-contained specialized unit combining the function of rock cutting, muck disposal and tunnel supporting equipment.

5. Tunnel Boring Machine reduces support requirement as there is less fracturing of rock along the periphery of tunnels.

6. Cost for TBM is high and all equipment has to be imported, and delivery of TBM to hydroelectric projects located in Himalayas involves a very long distance from *Port*, and infrastructure for transportation of TBM to site will mean reconstruction of many bridges etc.

7. It is usually difficult to find another tunnel of the same diameter to be bored in almost similar geologic conditions. Therefore, cutter-heads should be adjustable for meeting various conditions required. Otherwise, designed size of tunnel has to match with cutter head available or manufactured.

8. Excavation cost of tunnel per cu.m by conventional method in case of *Natpha-Jhakri*, has worked out to *Rs.1983/cu.m*, whereas by Tunnel Boring Machine (TBM) it is around *Rs.2404/cu.m.*

9. TBM is safer in operation, since no blasting is involved and surrounding of excavated rock is undisturbed. Accidents are also less.

10. Time schedule of *Nathpa-Jhakri* project using conventional tunneling method has been planned to be completed in about 4 years, because of *seven* adits available along of tunnel alignment and thus construction is facilitated from *nine* headings simultaneously at different places, whereas using a TBM it would have been completed in about 2.5 years.

    However, the saving in time may not be useful unless tunneling activity is on critical path of the project network. In case of *Nathpa-Jhakri* project, the tunneling activity *is not on critical path* and it may not serve any useful purpose to reduce the time taken for tunneling in this case. Therefore it may be concluded that in case of project where tunneling work is a critical activity on project network, it may be useful to consider the saving in construction time of tunnel by using TBM, thereby ensuring early completion of the project and thus benefit from the project can be reaped early.

APPENDIX – I

I.1 EXCAVATION OF NATHPA-JHAKRI TUNNEL

In *Nathpa-Jhakri* tunnel there are any methods of attack for excavation depends mainly upon the rock strata to be tackled and the type of equipment available on the project.

I.1.1 **Portals.**

Excavation of the portals should be properly planned and timed. The cut line marked on the plan should be demarcated at site and the deep excavation required for the portal should be examined from the view of dip and strike and possible slides either due to blasting in the lower reaches or due to rain water. Therefore, the final position of portals should be fixed according to the site condition. Sometimes it is better not to disturb the natural slope of the hill, which might cause landslide in rainy season. Therefore, at times it is better to bring out the portal site and construct a cut-and-cover section at the back.

No excavation work should be started till concreting arrangements are ready. It is essential that permanent portal should be constructed first and then excavation of the tunnel is started. If this is going to take much time, then temporary portals should be constructed. Such a work serves as buttress to the sloping hillside and affords good protection against slides. *(15)-p.94*

I.1.2. Heading and benching method

The Nathpa-Jhakri tunnel (*11.15 m*) diameter is *more than 8 meters*, it is advisable to do the excavation in *two stages* by *heading and benching* method, whether strata is good or bad. This method is both economical and easy. In the case of bad strata, any of the methods shown in **Fig.AI.1** are to be adopted and smooth blasting or pre-splitting technique has to be applied to the top periphery holes of the arch. In this method the actual tunneling operation is confined to the upper portion *6.5 meter* high, and the lower portion *4.5 m high* is excavated just like an open cut excavation after completing the first stage though the whole length of the tunnel. It means that there will be no ventilation problem at the time of carrying out the second-stage excavation. (15)-p.95

Method of excavation in Nathpa-Jhakri project proposed to be started after the completion of infrastructure works. *Seven* adits will be available along the tunnel alignment and will facilitate construction from *nine* heading simultaneously. (3)-p.ix-4

1.1.3. Steel ribs.

In bad strata, steel ribs are required to be used at spacing depending upon the nature of rock. **Fig AI-2** shows the use of steel ribs to be adopted in different strata.

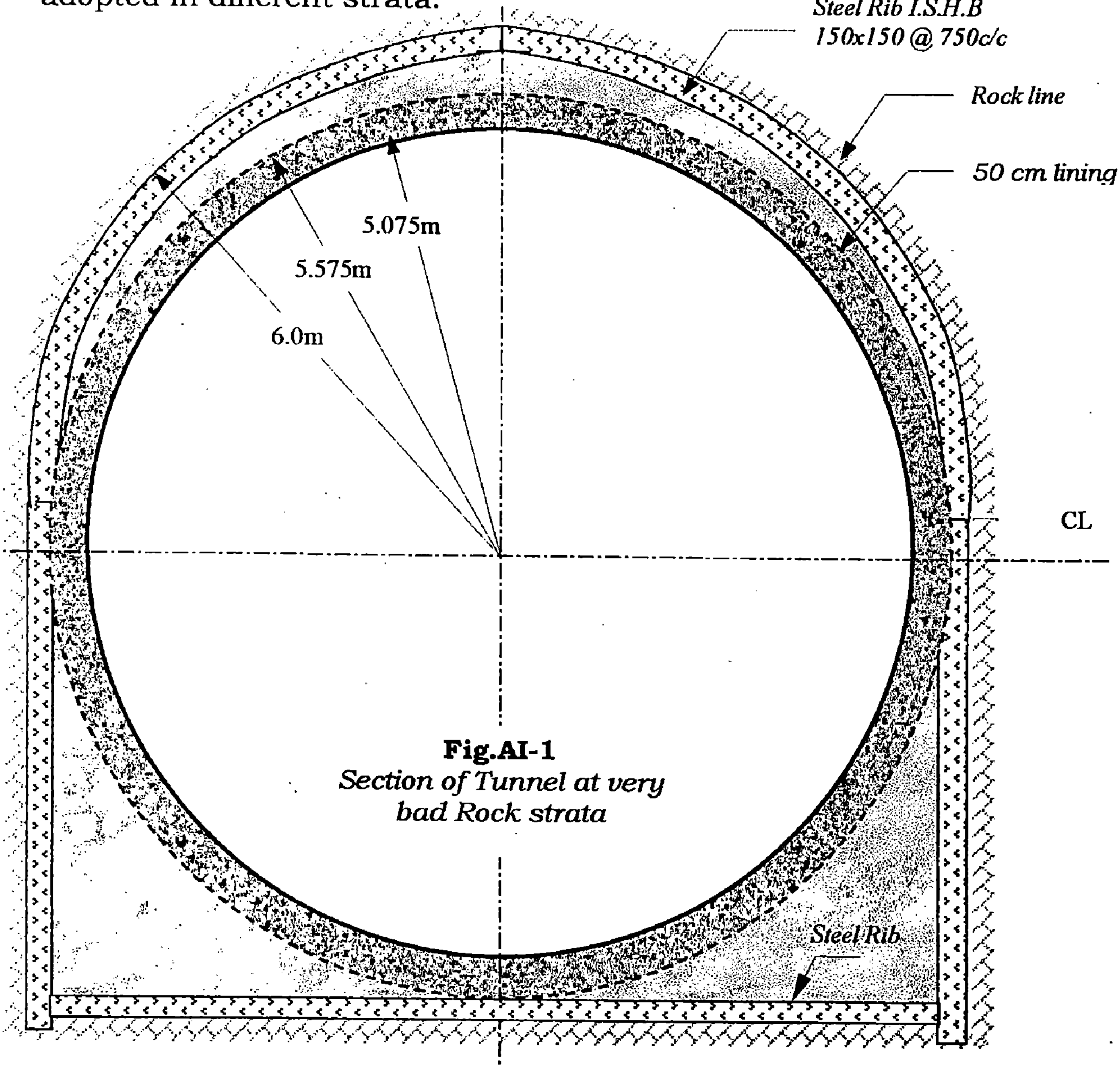


Fig.AI-1
Section of Tunnel at very bad Rock strata

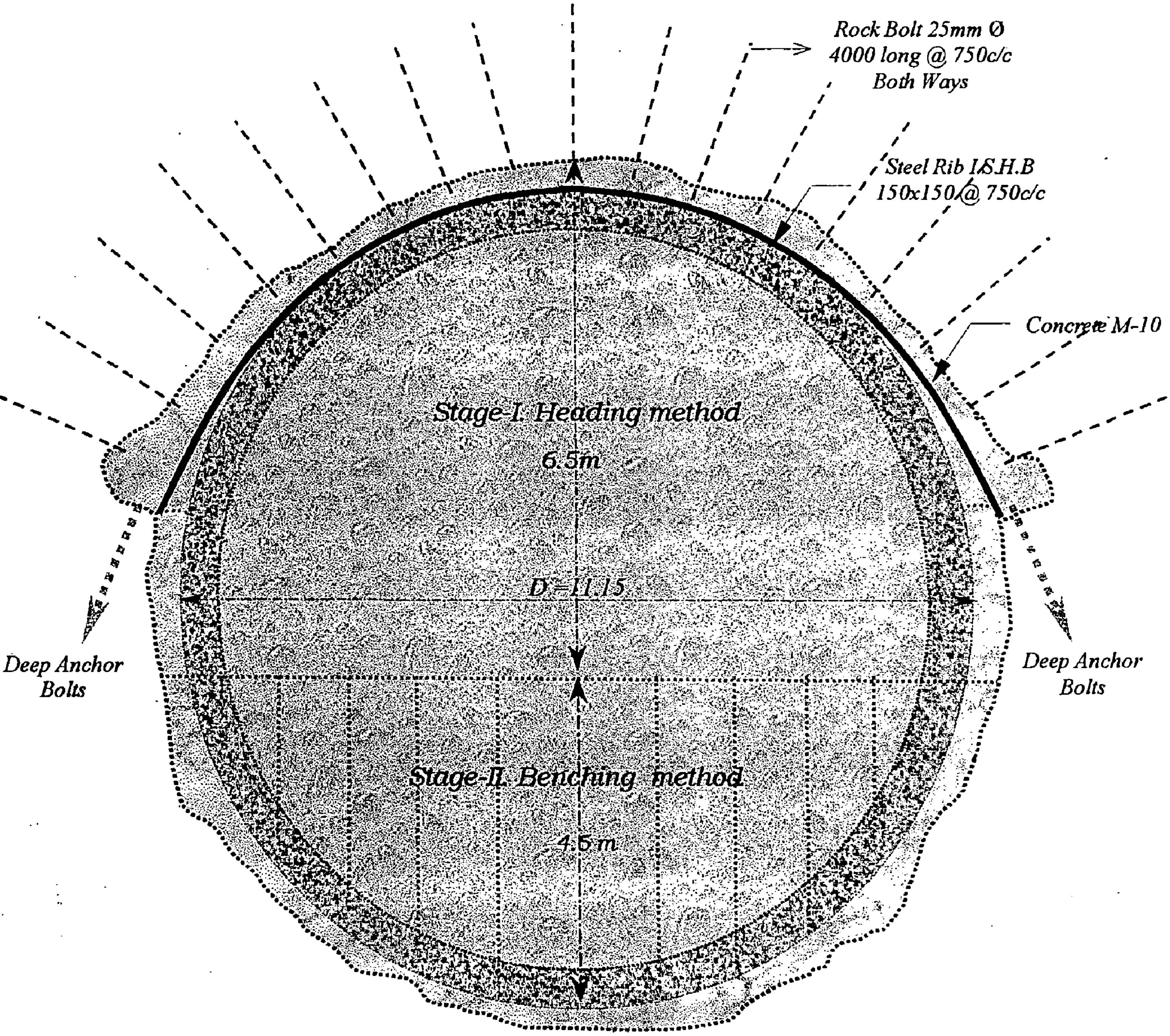


Fig.AI-2

11.15-meter diameter tunnel in jointed Good Rock.
Two Stages Excavation (Heading & Benching). (3)

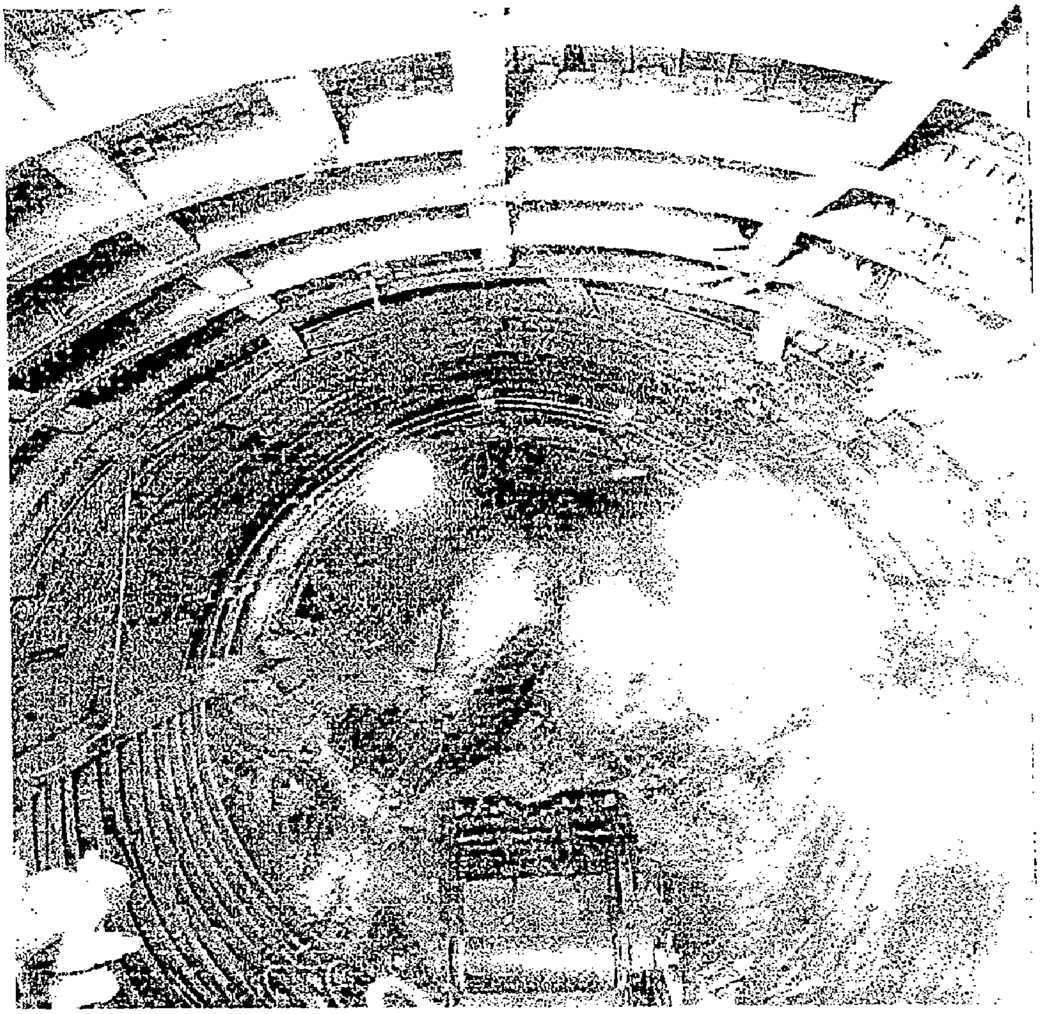


Fig.AI-3 *Heading and Benching Method.* (19)-p.131

The heading and benching method is used where rock will not permit full-face operations. In the illustration the tunnel is being driven through a fault zone with full circle support, flat wall plates and wall plate drifts.

Fig.AI-4 *Tunnel support in moderately blocky rock.* (19)-p.86

In the heading and benching method, (**Fig.AI-2**) a top heading is carried ahead of the bench about $^2/_3$ of diameter (6.5 *m*) height. Heading has the full width of the tunnel and should be carried down to the spring line. This method was standard for large tunnels prior to the advent of the drill carriage, as it provided a working surface on which to mount the drills for drilling the arch section of the face.

For the circular tunnel in bad strata, the reinforcement rings are so provided that about 80 % of the steel area of the circular ribs is also included in the reinforcement sectional area. In such cases, to have effective working of the ribs is erected at side; the other end of the plate is also welded to the next rib segment (***Fig.AI-5***).

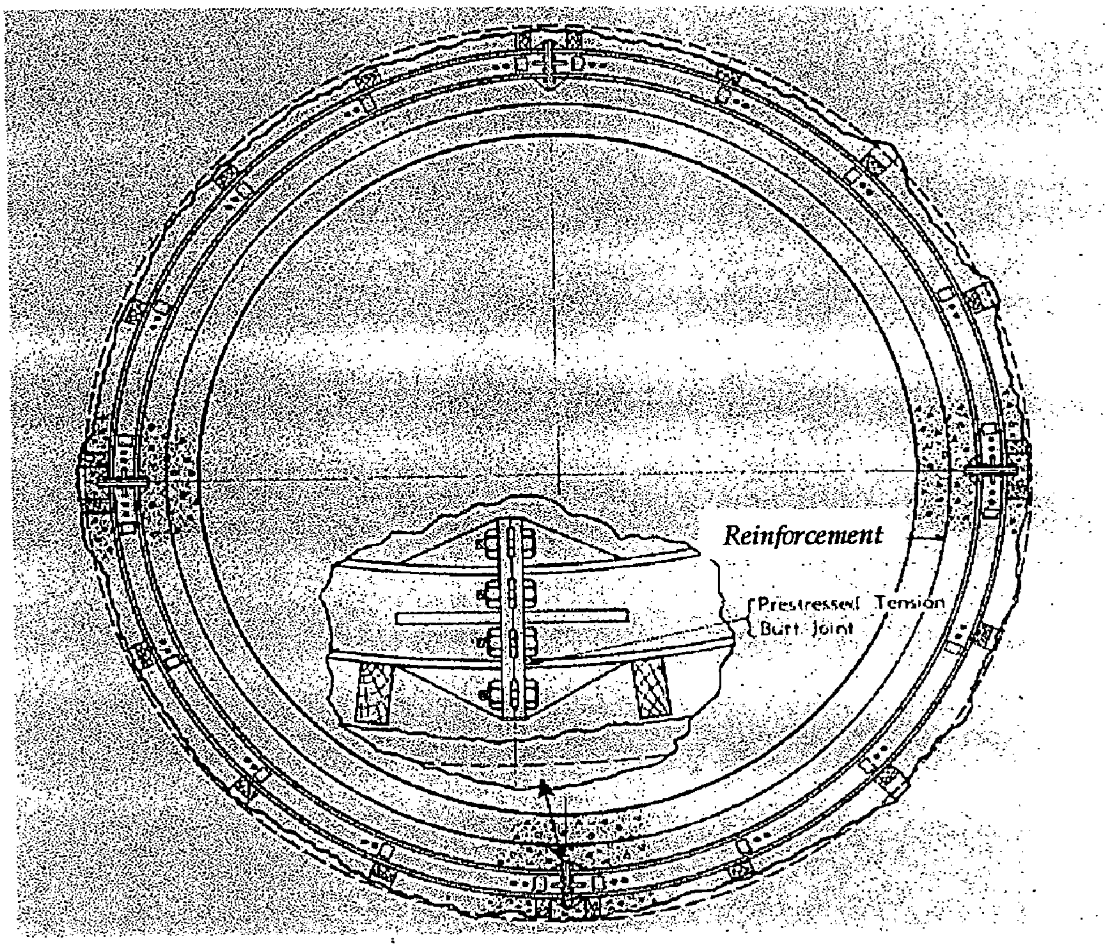


Fig.AI-5 *Steel support for the circular tunnel in bad strata* (19)-p.86

A.2. WORKING CYCLE

Following the *Nathpa-Jhakri Project*, cycle time of tunnelling is described as:

A. Cycle time for Heading:

a. Drilling time	=	1.50
b. Charging time	=	1.00
c. Blasting and defuming (exhaust).	=	1.00
d. Mucking	=	8.00
e. Rock bolting, rib erection and initial concreting	=	4.50
Total		16.00 hrs

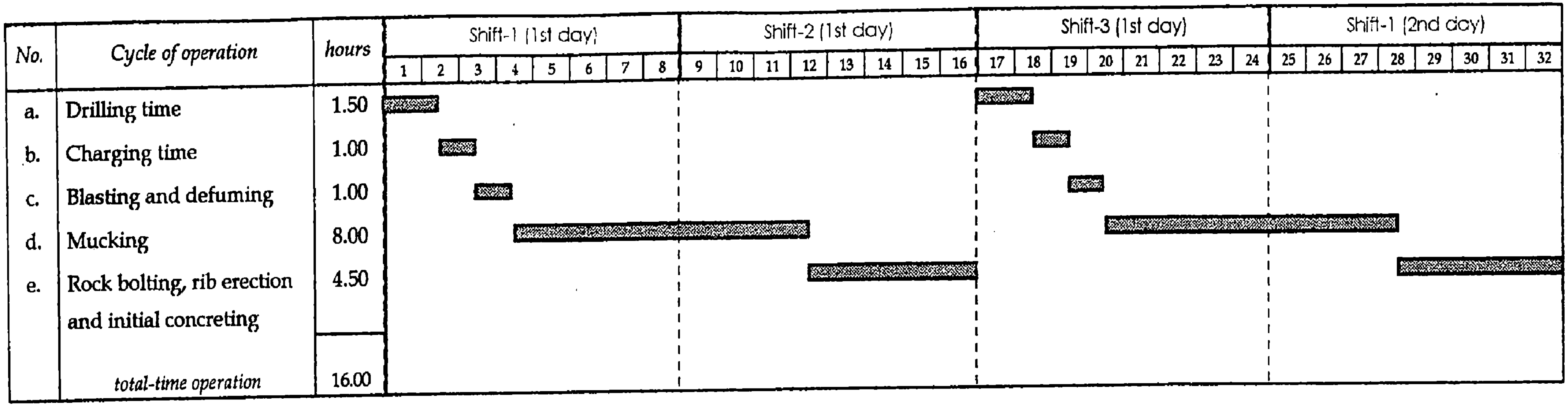
Average progress per face day (This includes drilling, blasting mucking, ribbing & packing etc.) is *4.5 m'/day*. And quantity of heading excavation *per cycle* of 3 m pull (16 hr/cycle) = 2/3 (¼ π x 11.15^2 m x 1.125 *over break*) x 3m′ = 220 cu.m.

B. Cycle time for Benching:

a. Drilling time	=	3.00
b. Charging time	=	1.00
c. Blasting and defuming (exhaust).	=	1.00
d. Mucking	=	7.00
Total		12.00 hrs

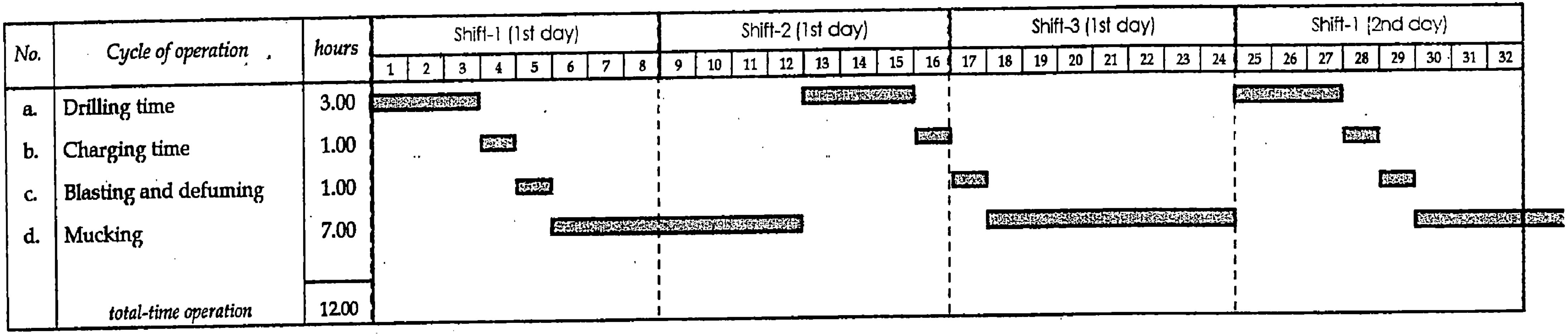
Average progress per face day (This includes drilling, blasting mucking, etc.) is *13.5 m/day'*. Quantity of excavation per day for benching (2 cycle) = 1/3 (¼ π x 11.15^2 m x 1.125 *over break*) x 13.5 m′ = 495 cu.m/day. Cycle time for heading and benching shown in ***Fig.AI.6***, and the project network planning is given in ***Fig.AI-7***.

Working cycle for Heading method



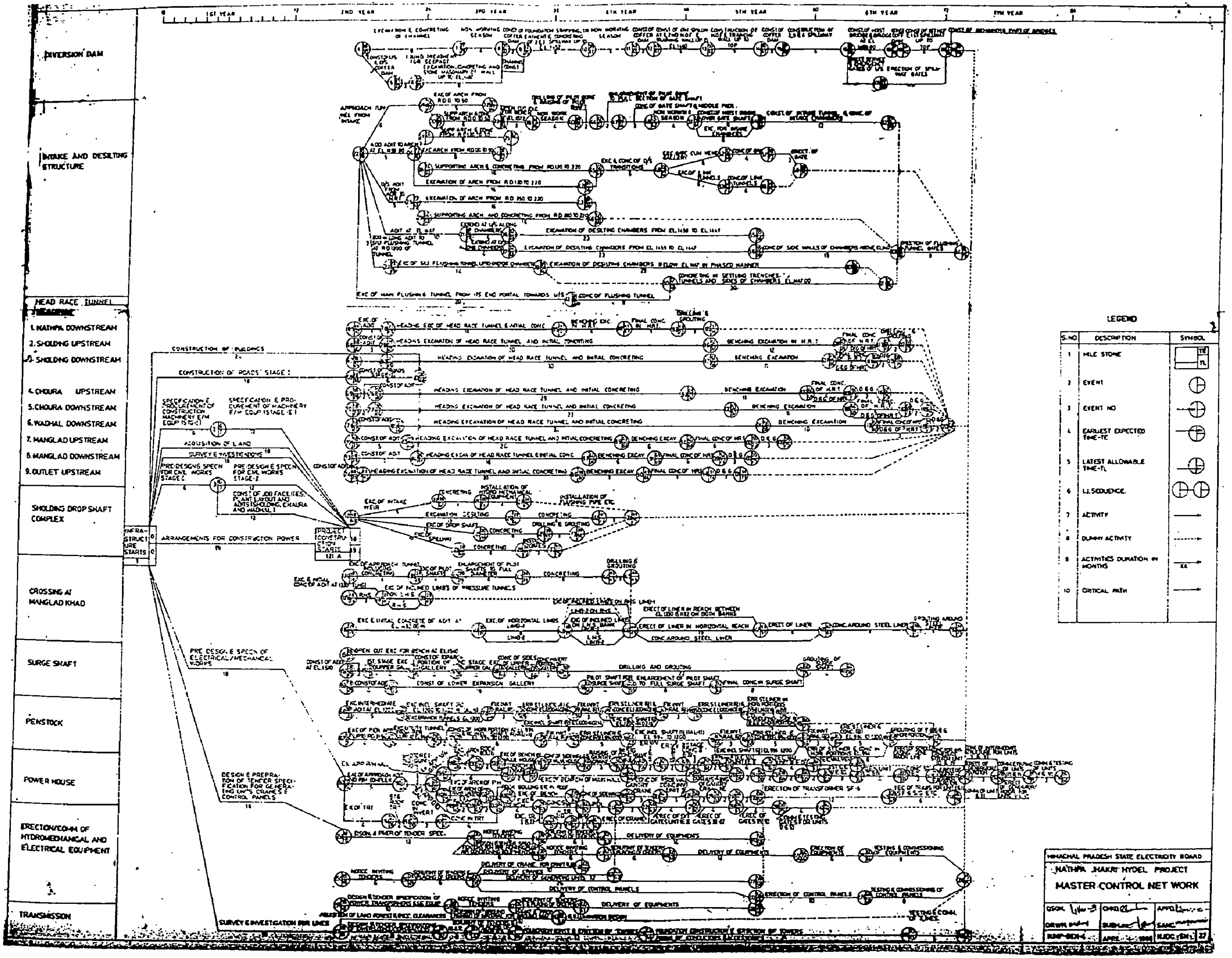
No.	Cycle of operation	hours
a.	Drilling time	1.50
b.	Charging time	1.00
c.	Blasting and defuming	1.00
d.	Mucking	8.00
e.	Rock bolting, rib erection and initial concreting	4.50
	total-time operation	16.00

Working cycle for Benching method



No.	Cycle of operation	hours
a.	Drilling time	3.00
b.	Charging time	1.00
c.	Blasting and defuming	1.00
d.	Mucking	7.00
	total-time operation	12.00

Fig.AI-6*. *Working cycle for heading and benching method



LEGEND

S.NO.	DESCRIPTION	SYMBOL
1	MILE STONE	TE / TL
2	EVENT	⊕
3	EVENT NO	⊕
4	EARLIEST EXPECTED TIME-TE	⊕
5	LATEST ALLOWABLE TIME-TL	⊕
6	LL SEQUENCE.	⊕–⊕
7	ACTIVITY	→
8	DUMMY ACTIVITY	---→
9	ACTIVITIES DURATION IN MONTHS	→ XX
10	CRITICAL PATH	→

HIMACHAL PRADESH STATE ELECTRICITY BOARD
NATHPA JHAKRI HYDEL PROJECT
MASTER CONTROL NET WORK

DSGN.	CHKD.	APPD.
DRWN.	SUBD.	SANC.
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APPENDIX - II

I. Detail Cost of Conventional Method.

A. *ABSTRACT OF CHARGES FOR HEADING.*

1.	Direct labour charges.	=	Rs.	**53.00**
2.	Material charges.	=	Rs.	**789.80**
3.	Ventilation blower charges.	=	Rs.	**30.95**
4.	Shop charges.	=	Rs.	**306.00**
5.	Machinery charges.	=	Rs.	**312.65**
6.	Electrical material charges/cu.m	=	Rs.	**75.00**
7.	Jumbo track charges/cu.m	=	Rs.	**75.00**
8.	Compressed air charges/cu.m	=	Rs.	**75.00**
9.	Water charges/cu.m	=	Rs.	**75.00**
	Total charges :		Rs.	**1792.40**
		say	Rs.	*1792*
•	Add for construction and maintenance of haul road at 4 % of total charges.	=	Rs.	71.70
•	Add for electric energy charges at 2 % of total charges	=	Rs.	35.85
	Prime cost	=	Rs.	**1900**
•	Add overhead charges and contractor's proffit at 20 % of prime cost.	=	Rs.	379.99
	Grand Total :	=	Rs.	**2,279.94**
		say	Rs.	2,280

Hence, rate per cu.m = Rs. 2,280

1. Detail Cost of Conventional Method.

Tunnel excavation is proposed to be carried out by heading and benching method. A 6.5 m deep heading will be excavated in the first instance. The bottom portion shall be taken up in benching operation subsequently.

The abstract of cost given is based on the rates provided in *Nathpa-Jhakri modified report* (1986), which have been increased by 300% to take into account the cost of inflation. Interest 7% compounded annually, yielding $(1+0.07)^{16}$ equal to 3 times increase

1. Finished dia. of tunnel = 10.15 meter
2. Excavated dia. = 11.15 meter
3. Excavated section = $(\pi / 4) \times 11.15^2$ = 97.64 sqm
4. Exc.Qty/m length of HRT
   with 12.5 % over break = 109.85 = 110 sqm
5. Exc.Qty in heading / m = ⅔ (110) = 73.33 sqm
6. Exc.Qty in benching = ⅓ (110) = 36.67 sqm
7. Rock excavation in heading in HRT = **2,280** Rs/cu.m
   (as per rock excavation in heading)
8. Rock excavation in benching in HRT = **1,380** Rs/cu.m
   (as per rock excavation in benching)
9. Therefore average rate of excavation in HRT /cum

$$\frac{(73.33 \times 2280 + 36.67 \times 1380)}{110} = 1982.58 \text{ Rs/cu.m}$$

say *1983* Rs/cu.m

A. Rock Excavation in Heading in Head Race Tunnel (per cum)

- Quantity of excavation per meter length of tunnel = 73.33 sqm
- Average progress per face day (This includes drilling, blasting mucking, ribbing & packing etc.) = 4.5 m
- Quantity of excavation per cycle of 3 m pull (16 hr/cycle) 73.33 x 3 = 220 cu.m
- No.of working shifts of 8 hour each/day = 3 Nos
- Quantity of excavation per shift of 8 hours = 110 cu.m
- Quantity of excavation/day/face 110 x 3 = 330 cu.m

Cycle of operation	*No. of working hours*	
a. Drilling time	= 1.50	hrs
b. Charging time	= 1.00	hr
c. Blasting and defuming	= 1.00	hr
d. Mucking	= 8.00	hrs
e. Rock bolting, rib erection and initial concreting	= 4.50	hrs
Total	16.00	hrs

1. *Direct Labour Charges (per day)*

• 1 No. Foreman special drilling at Rs.300 per day	=	Rs.	300
• 1 No. Assistant Foreman special drilling at Rs.240 per day	=	Rs.	240
• 1 No. Explosive Inspector at Rs.240 per day	=	Rs.	240
• 1 No. Electrician at Rs.200 per day	=	Rs.	200
• 1 No. Blastman at Rs.200 per day	=	Rs.	200
• 1 No. Hole cleaner at Rs. 160 per day	=	Rs.	160
• 1 No. helper to electrician at Rs. 120 per day	=	Rs.	120
• 40 Nos. mucker at Rs. 120 per day	=	Rs.	4800
• 40 Nos. beldars at Rs, 120 per day	=	Rs.	4800
• 1 No. Wireman for blasting at Rs.200 per day	=	Rs.	200
• 2 Nos. Explosive chargeman at Rs.200 per day	=	Rs.	400
Total wages	=	Rs.	11660
Add for hidden cost of labour at 50 % of direct labour charges.	=	Rs.	5830
Total direct labour	=	Rs.	17,490

Rate of labour per cu.m $\frac{\textit{Total direct labour}}{330}$ = Rs. **53**

2. *Material Charges :*

2.1. *Drillning and blasting :*

a. It is proposed that to attain 4.5 m progress per day per face 3.00 deep hole will be drilled.

• Cross section area of tunnel	=	73.33	*Sqm.*
• No. of holes required per face	=	140	*holes*
• Total depth of drilling 140 x 3.6	=	504	*meters*
• Cost of drill steel per meters	=	Rs.	*30*
• Cost of drill steel = 30 x 504	=	Rs.	*15120*
• Quantity of rock excavated	=	330	*cu.m*

- Rate for drill steel per cu.m :

$$\frac{\textit{Total cost of drill steel}}{330} = \frac{15120}{330} = 45.82 \text{ Rs./cu.m}$$

b. Explosives :

(i) Gelatine required per cu.m	=	1.25	*Kg*
Cost of gelatine per Kg.	=	150	*Rs.*
Rate per cu.m (1.25 x cost of gelatine per Kg)	=	*187.5*	*Rs./cu.m*

(ii) Detonator and fuse coils:

No. of detonators and fuse coils at one / hole /face = 140 *nos.*

Cost of 140 nos. detonator and fuse coil at Rs.30 each = 4200 *Rs.*

Quantity of rock excavated = 330 *cu.m*

Hence rate of explosive per cu.m = $\frac{4200}{330}$ = *12.7* *Rs./cu.m*

(iii) Other consumable petty stores such as blasting batteries, galvanometers and blasting wires etc. at 50 % of item (i) = *93.75* *Rs./cu.m*

Total explosive charges per cum (i)+(ii)+(iii) = *294.0* *Rs./cu.m*

Total drilling and blasting charges (a+b) = *339.8* *Rs./cu.m*

2.2 *Provision of pipe line for air and* water for wet drilling

Rate per cu.m L.s. = 150 *Rs.*

2.3 *Timber for supports packing*

Rate per cu.m L.s. = 150 *Rs.*

2.4 *Miscellaneous supplies such as safety hats,* gumboots, rain coats, wire ropes, manila ropes, U-clamps, rubber gloves, shockless and artificial respiraters etc.

Rate per cu.m L.s = 150 *Rs.*

Total material charges per cu.m (A+B+C+D) = *789.8* *Rs.*

3. *Charges for ventilation blowers:*

(a) Depreciation charges :

- Total cost of blower / axial fans including cost of accessories such as air duct, = Rs. 1,500,000
- Rated life = 15000 hours
- Depreciation charges per hour : $\frac{1,500,000}{15000}$ = Rs. *100.00*

(b.) Repair and maintenance charges at 100 % of depreciation per hour = Rs. *100.00*

(c.) P.O.L Charges :

Horse power of blowers = 100 H.P

Energy required per hour = 100 x 0.746 = 74.60 KWH

say 75 KWH

Cost of 75 KWH energy at Rs. 2,-/ per KWH = Rs. 150.00

Sundries and other items L.s = Rs. 15

Total POL charges = Rs. *165.00*

(d) Labour charges:

1 No. operator at Rs.200 per day		=	Rs.	200
1 No. helper at Rs.120 per day		=	Rs.	120
	Sub total of wages	=	Rs.	320

- Add for hidden cost of labour at 50 % of direct labour charges. = Rs. 160
- Total labour charges. = Rs. 480
- No. of working hours per shift 8
- Labour charges per hour : $\frac{\textit{grand total of wages}}{8}$ = Rs. *60*

- Total charges = (a + b + c + d) per working hour = Rs. *425.00*
- No. of working hours of blowers per shift = 8
  Total charges of blowers per shift
  = 8 x total blower charges/hr. = Rs. 3400.00
- Rock excavated per shift (*Sq.m*) : 110

Hence rate per cum : $\frac{\text{Total blower charges/shift}}{110}$ = Rs. **30.95**

4. Shop charges:

a.	Machineshop including foundry and smithy	L.s.	=	Rs.	36
b.	Structural shop	L.s.	=	Rs.	75
c.	Steel metal shop	L.s.	=	Rs.	75
d.	Air and water pipe shop	L.s.	=	Rs.	60
e.	Carpentary shop	L.s.	=	Rs.	60
	Total shop charges per cu.m		=	Rs.	**306**

6.	*Electrical material charges/cu.m*	L.s.	=	Rs.	**75**
7.	*Jumbo track charges/cu.m*	L.s.	=	Rs.	**75**
8.	*Compressed air charges/cu.m*	L.s.	=	Rs.	**75**
9.	*Water charges/cu.m*	L.s.	=	Rs.	**75**

5. Machinery Charges for Heading

No.	Equipment	Nos.	Working hours per cyles	Total working hours/day	Use rate per hour in Rs.	Amount in Rs.
1.	3 boom Hydraulic Jumbo	1	2.25	2.25	6,000	13,500
2.	Muck Cars	9	12	108	28	3,013
3.	Jack Hammers	6	1.5	9	440	3,959
4.	Grinders	2	2	4	60	240
5.	Convey mucker (1.15 cum)	2	12	24	1,596	38,303
6.	Battery Loco 20 T	2	10	20	707	14,146
7.	Tractor Dozer 200 HP	1	10	10	2,886	28,856
8.	Battery Loco 3 T	1	3	3	386	1,159

Total Machinary charges : = Rs. **103,176**

Quantity of Rock Excavated 330 cum

Rate per cu.m : $\frac{\text{Total machiner charges}}{330} = \frac{103176}{330}$

= Rs. **312.65**

(per cum)

5. Machinery Charges for Benching

No.	Equipment	Nos.	Working hours per cyles	Total working hours/day	Use rate per hour in Rs.	Amount in Rs.
1.	Track Drilling	1	5	5	3,000	15,000
2.	Jack Hammers	6	5	30	440	13,197
3.	Convey mucker (1.15 cum)	1	15	15	1,596	23,939
4	Muck Car 10 cu.m	10	15	150	28	4,185
5	Battery Loco 20 T	2	18	36	707	25,463
6	Tractor Dozer 200 HP	1	10	10	2,886	28,856
7	Battery Loco 3 T	1	9	9	386	3,477

Total Machinary charges : = Rs. **114,117**

Quantity of Rock Excavated 495 cum

Rate per cu.m : $\frac{\text{Total machiner charges}}{495} = \frac{114117}{495}$

= Rs. **230.54**

(per cum)

B. ABSTRACT OF CHARGES FOR BENCHING

1.	Direct labour charges.	=	Rs.	35.33
2.	Material charges.	=	Rs.	*686.88*
3.	Ventilation blower charges.	=	Rs.	*6.87*
4.	Shop charges.	=	Rs.	*55.00*
5.	Machinery charges.	=	Rs.	*230.54*
6.	Electrical material charges/cu.m	=	Rs.	*20.00*
7.	Jumbo track charges/cu.m	=	Rs.	*20.00*
8.	Compressed air charges/cu.m	=	Rs.	*20.00*
9.	Water charges/cu.m	=	Rs.	*10.00*
	Total charges :		Rs.	*1,084.62*
		say	Rs.	*1085*

• Add for construction and maintenance of haul road at 4 % of total charges.	=	Rs.	43.38
• Add for electric energy charges at 2 % of total charges	=	Rs.	21.69
Prime cost	=	Rs.	1150
• Add overhead charges and contractor's proffit at 20 % of prime cost.	=	Rs.	229.94
Grand Total :	=	Rs.	1,379.64
	say	Rs.	1,380

Hence, rate per cu.m = Rs. 1,380

B. *Rock Excavation in Benching in Head Race Tunnel (per cum) :*

Total area of tunnel excavation = 110 Sq.m
Less area of heading = 73.33 Sq.m
Net benching area = 36.67 Sq.m
Progress per day = 13.5 m
Quantity of excavation per day
(2 cycles) 36.67 x 13.5 = 495 cu.m

1. *Direct labour charges :*

- Direct labour charges per day. = Rs. 17,490
  (same as per item A-for rock excavation in heading)
- Rate of labour per cu.m $\frac{17,490}{495}$ = Rs. 35.33

2. *Material Charges:*

2.1 *Drilling and Blasting :*

a. It is proposed to attain 13.5 meters progress per day per face 1.8 m deep holes will be drilled.

- No. of holes required per face = 70 Nos.
- Total depth of drilling (70 x 1.8 m) = 126 m.
- Cost of drilling steel (126 x 30) = 3,780 Rs.
- Quantity of rock escavated = 495 cu.m
- Rate for drill steel per cu.m = $\frac{3780}{495}$ = 7.6 Rs/cu.m

b. Explosive :

(i) Gelatine required per cu.m = 1.00 *Kg*
Cost of gelatine per Kg. = 150.0 *Rs.*
Rate per cu.m (1.0 x cost of gelatine per Kg) = *150.0 Rs./cu.m*

(ii) Detonator and fuse coils:
No. of detonators and fuse coils at one / hole /face = 70 *nos.*
Cost of 70 nos. detonator and fuse coil at Rs.30 each = 2100 *Rs.*
Quantity of rock excavated = 495 *cu.m*
Hence rate of explosive per cu.m = $\frac{2100}{495}$ = 4.24 *Rs./cu.m*

(iii) Other consumable petty stores such as blasting batteries, galvanometers and blasting wires etc. at 50 % of item (i) = *75 Rs./cu.m*
Total explosive charges per cum (i)+(ii)+(iii) = *229.2 Rs./cu.m*
Total drilling and blasting charges (a+b) = *236.9 Rs./cu.m*

2.2 *Provision of pipe line for air and* water for wet drilling

Rate per cu.m L.s. = *150* *Rs.*

2.3 *Timber for supports packing*

Rate per cu.m L.s. = *150* *Rs.*

2.4 *Miscellaneous supplies such as safety hats,* gumboots, rain coats, wire ropes, manila ropes, U-clamps, rubber gloves, shockless and artificial respiraters etc.

Rate per cu.m L.s = *150* *Rs.*

Total material charges per cu.m (A+B+C+D) = *686.9* *Rs.*

3. *Charges for ventilation Blowers :*

Amount same as per item (*A* - 4) = Rs. *3400.00*

Hence, Rate per cu.m = $\frac{3400.00}{495}$ = Rs. *6.87*

4. *Shop charges:*

a. Machineshop including foundry and smithy L.s. = Rs. 15
b. Structural shop L.s. = Rs. 10
c. Steel metal shop L.s. = Rs. 10
d. Air and water pipe shop L.s. = Rs. 10
e. Carpentary shop L.s. = Rs. 10

Total shop charges per cu.m = Rs. 55

6. *Electrical material charges/cu.m* L.s. = Rs. ***20***
7. *Jumbo track charges/cu.m* L.s. = Rs. ***20***
8. *Compressed air charges/cu.m* L.s. = Rs. ***20***
9. *Water charges/cu.m* L.s. = Rs. ***10***

ANALYSIS OF RATES FOR WORKING OF MACHINERY [(3)]

1 Dozer 200 H.P Class

A.	Depreciation charges :				
a.	Cost of machine at site including freight insurance and all items	Rs = 7,500,000			
b.	Life of machine in hours	12000 hrs			
c.	life in years	10 years			
d.	Depreciation charge/hr	$\frac{7,500,000 \times 0.90}{12000}$	=	Rs.	**562.50**
B.	Repair and Maintenance charge at 240 % of depreciation charge		=	Rs.	**1,350.00**
C.	P.O.L Charges	180			
	Rate H.P				
	Consumption of diesel oil = 0.026 x 4.546 x 180		=	Rs.	21.28
a.	Cost of 0.25 liter hydraulic oil at Rs. 100.00/liter		=	Rs.	25.00
b.	Cost of 21.27 liters diesel at Rs. 18/liter		=	Rs.	382.86
c.	Cost of 1 liter petrol at Rs. 30/liter		=	Rs.	30.00
d.	Cost of 0.75 liter lubrication oil at Rs.100.00/liter		=	Rs.	75.00
e.	Cost of 0.60 liter filter oil at Rs.80.00/liter		=	Rs.	48.00
f.	Cost of 0.25 liter Gear oil at Rs. 112.00/liter		=	Rs.	28.00
g.	Cost of 0.50 kg Grease at 112.00 per Kg.		=	Rs.	56.00
		Total of stores	=	Rs.	666.14
	Service and micellaneous charges at 15 % of stores 168.10		=	Rs.	99.92
				Rs.	**766.06**
D.	Labour charges				
	Rated life in hrs/yr	$\frac{12000}{10}$ = Rs 1200			
a.	Foreman 1/4 No.	$\frac{\text{MRx12x1}}{\text{1200x4}} = \frac{\text{7200x12}}{\text{1200x4}}$	=	Rs.	18.00
b.	Mechanic 1/4 No.	$\frac{\text{MRx12x1}}{\text{1200x4}} = \frac{\text{6000x12}}{\text{1200x4}}$	=	Rs.	15.00
c.	Helper 1 No.	$\frac{\text{MRx12x1}}{\text{1200x1}} = \frac{\text{3600x12}}{\text{1200}}$	=	Rs.	36.00
d.	Wacthman 1/4 No.	$\frac{\text{MRx12x1}}{\text{1200x4}} = \frac{\text{3600x12}}{\text{1200x4}}$	=	Rs.	9.00
e.	Operator 1 No.	$\frac{\text{MRx12x2}}{\text{1200x1}} = \frac{\text{6000x12}}{\text{1200}}$	=	Rs.	60.00
		Total	=	Rs.	138.00
	Direct labour charges		=	Rs.	138.00
	Add for hidden cost of labour at 50 % of direct labour charges		=	Rs.	69.00
	Total labour charges		=	Rs.	**207.00**
	Hence, hourly use rate of Dozer (A+B+C+D)		=	Rs.	**2,885.56**
	Say Rupees =	*2,886 /hr.*			

2 *Convey mucker (1.15 cum)*

A. Depreciation charges

I. Machine

a. Cost of machine (excludeing belt) at site = Rs. 5,400,000.00

b. Rated life 15000 hrs

c. Life in years 10 year

Depreciation charge/hr $\frac{5,400,000 \times 0.90}{15000}$ = Rs. 324.00

II. Belt

a. Cost of the belt at site = Rs. 300,000

b. Life 3000 hrs

c. Depreciation of Belt /hr $\frac{\text{cost}}{3000}$ = Rs. 100.00

Total depreciation (I+II) = Rs. **424.00**

B. Repair and Maintenance charges

a. Machine (excluding belt) at 100 % of depreciating charges = Rs. 324.00

b. Belt, at 45 % depreciation charges = Rs. 45.00

Total repairs and maintenance charges = Rs. **369.00**

C. P.O.L Charges (H.P 330)

Electrical energy required = 330 x 0.746 = 246.18 KWH

a. Charges of electrical energy at Rs. 2,-/unit = Rs. 492.36

b. Lubricants etc. at 25 % of (a) above = Rs. 123.09

c. Sundries and miscellaneous supplies at 10 % of (B) = Rs. 36.90

Total POL charges = Rs. **652.35**

D. Labour charges

Rated life in hrs / yrs $\frac{15000}{10}$ = 1500

a. Operator $\frac{MRx12x1}{1500 \times 1} = \frac{6000 \times 12 \times 1}{1500 \times 1}$ = Rs. 48.00

b. Helper $\frac{MRx12x1}{1500 \times 1} = \frac{3600 \times 12 \times 1}{1500 \times 1}$ = Rs. 28.80

c. Foreman $\frac{MRx12x1}{1500 \times 8} = \frac{7200x12x1}{1500 \times 8}$ = Rs. 7.20

d. Mechanic $\frac{MRx12x1}{1500 \times 6} = \frac{6000x12x1}{1500 \times 6}$ = Rs. 8.00

d. Chowkidar $\frac{MRx12x1}{1500 \times 4} = \frac{4200x12x1}{1500 \times 4}$ = Rs. 8.40

Direct Labour charges = Rs. 100.40

Add for hidden cost of labour at 50% of direct labour charges = Rs. 50.20

Total labour charges = Rs. **150.60**

Hourly use rate of Convey mucker (A+B+C+D) = Rs. **1,595.95**

Say Rupees = *1,596 /hr.*

3 *Jack Hammer*

A.	Depreciation charges					
a.	Total cost of jack Hammer at site including all taxes, freight and insurance.	= Rs.	21,000			
b.	Life of Jack Hammer in years		10	year		
c.	Rated Life of Jack Hammer in hour		10,000	hour		
	Depreciation charge/hr		$\frac{21,000 \times 0.90}{10000}$	=	Rs.	**1.89**
B.	Repairs and maintenance at 60 % of depreciation charges of machine			=	Rs.	**1.13**
C.	P.O.L Charges Compressed air at 120 cfm					
a.	Cost of compressed air at at Rs.750/500 cfm	=	$\frac{120 \times 750}{500}$	=	Rs.	180.00
b.	Lubricants and grease of item (a) above at 25 %			=	Rs.	45.00
c.	Sundries and misc.supplies at 10 % of item (B) above			=	Rs.	0.11
d.	Pneumatic rubber hose pipe 38 mm with fittings 15 m at Rs.150 / 100 meter working hours			=	Rs.	22.50
	Total POL charges (a+b+c+d)			=	Rs.	**247.61**
D.	Labour charges					
	Rated life in hours / years $\frac{10000}{10}$	=	1000			
a.	Operator $\frac{MRx12x1}{1000 \times 1}$	=	$\frac{6000 \times 12 \times 1}{1000 \times 1}$	=	Rs.	72.00
b.	Helper $\frac{MRx12x1}{1000 \times 2}$	=	$\frac{3600 \times 12 \times 1}{1000 \times 2}$	=	Rs.	21.60
c.	Supervisor $\frac{MRx12x1}{1000 \times 5}$	=	$\frac{7200x12x1}{1000 \times 5}$	=	Rs.	17.28
d.	Mechanic $\frac{MRx12x1}{1000 \times 8}$	=	$\frac{6000x12x1}{1000 \times 8}$	=	Rs.	9.00
d.	Chowkidar $\frac{MRx12x1}{1000 \times 8}$	=	$\frac{4200x12x1}{1000 \times 8}$	=	Rs.	6.30
			Total	=	Rs.	126.18
	Add for hidden cost of labour at 50 % of Direct Labour Charges			=	Rs.	63.09
					Rs.	**189.27**
	Hourly use rate of Jack Hammer (A+B+C+D)			=	**Rs.**	**439.91**

Say Rupees = **440** */hr.*

4 *Locomotive battery 20 Tonnes*

A. Depreciation charges

a. Total capital cost of locomotive including all taxes, freight and insurance.	= Rs. 9,000,000			
b. Life in years	22	year		
c. Rated Life	40,000	hour		
d. Depreciation charge/hr	$\frac{9,000,000 \times 0.90}{40,000}$	=	Rs.	**202.50**

B. Repairs and maintenance charges at 100 % of cost of equipment / hr	=	Rs.	**202.50**

C. P.O.L Charges

a. Battery set is charged after every 5 hrs. Electric charges including other misc. charges / hr.L.S		=	Rs.	90.00
b. Battery set				
Cost of 2 sets of Batteries	Rs. 270,000			
Life	6000 hr			
Depreciation charges	$\frac{270,000 \times 0.9}{6000}$	=	Rs.	40.50
Lubrications etc. at 25% of sub item (a) above		=	Rs.	22.50
Sundries and Misc. supplies at 10 % of item (B)		=	Rs.	20.25
	Total	=	Rs.	**173.25**

D. Labour charges

Rated life in hours / years	$\frac{40000}{22.00}$	=	1818 *(hr / yr)*	say	Rs.	1,820
a. Operator 1 No.	$\frac{MR\times12\times1}{1820 \times 1}$	=	$\frac{6000 \times 12 \times 1}{1820 \times 1}$	=	Rs.	39.56
b. Helper 1 No.	$\frac{MR\times12\times1}{1820 \times 1}$	=	$\frac{3600 \times 12 \times 1}{1820 \times 1}$	=	Rs.	23.74
c. Foreman 1/8 Nos.	$\frac{MR\times12\times1}{1820 \times 8}$	=	$\frac{7200\times12\times1}{1820 \times 8}$	=	Rs.	5.93
d. Mechanic 1/4 Nos.	$\frac{MR\times12\times1}{1820 \times 4}$	=	$\frac{6000\times12\times1}{1820 \times 4}$	=	Rs.	9.89
d. Chowkidar 1/4 Nos.	$\frac{MR\times12\times1}{1820 \times 4}$	=	$\frac{4200\times12\times1}{1820 \times 4}$	=	Rs.	6.92
			Total	=	Rs.	86.04
Add for hidden cost of labour at 50 % of Direct Labour Charges				=	Rs.	43.02
					Rs.	**129.07**

Hourly use rate of Jack Hammer (A+B+C+D)	=	**Rs.**	**707.32**

Say Rupees = 707 /hr.

5 *Muck Car (10 cum capacity)*

A.	Depreciation charges						
	a. Cost of muck car at site	Rs.	600,000				
	b. Life of muck car in years		20	year			
	c. Rated Life of muck car in hrs.		30,000	hour			
	d. Depreciation charge/hr	$\frac{600,000 \times 0.90}{30,000}$			=	Rs.	**18.00**
B.	Repairs and maintenance charges at 50 % of depreciation				=	Rs.	**9.00**
C.	P.O.L Charges						
	Feul & Lubricant				=	Rs.	NIL
	Sundries etc. at 10 % of (B) above				=	Rs.	0.90
D.	Labour charges						
	Use rate of muck car /hr (A+B+C)				=	Rs.	27.90

Hourly use rate of Jack Hammer (A+B+C+D)

Say Rupees = 28 /hr.

6 ***Motor Grader-150 H.P***

A. Depreciation charges

a. Cost of machine at site including freight, insurance and all taxes = Rs. 4,500,000
b. Life of machine in hour 12000 hrs
c. Life in years 10 year
Depreciation charge/hr $\frac{4,500,000 \times 0.90}{12000}$ = Rs. **337.50**

B. Repair and Maintenance charges at 150 % of depreciation charges = Rs. **506.25**

C. P.O.L Charges (H.P 330)

10 liters diesel at Rs. 18.00 /liter	=	Rs.	180.00
0.45 liters mobile oil at Rs. 100.00 / liter	=	Rs.	45.00
0.15 liters Gear oil at Rs. 112.00 /liter	=	Rs.	16.80
0.05 liter break oil at Rs. 220.00 liter	=	Rs.	11.00
0.1 grease at Rs.112.00 / Kg.	=	Rs.	11.20
Total	=	Rs.	264.00
Fueling service charges per hour	=	Rs.	2.00
Lubricant service charge per hour	=	Rs.	6.00
Total	=	Rs.	**272.00**

D. Labour charges

Rated life in hrs / yrs $\frac{12000}{10} = 1200$

a. Operator	$\frac{MRx12x1}{1200 \times 1}$	$= \frac{6000 \times 12 \times 1}{1200 \times 1}$	=	Rs.	60.00
b. Foreman	$\frac{MRx12x1}{1200 \times 3}$	$= \frac{7200x12x1}{1200 \times 3}$	=	Rs.	24.00
d. Mechanic	$\frac{MRx12x1}{1200 \times 3}$	$= \frac{6000x12x1}{1200 \times 3}$	=	Rs.	20.00
d. Helper/Greaser	$\frac{MRx12x1}{1200 \times 1}$	$= \frac{3600x12x1}{1200 \times 1}$	=	Rs.	36.00
Direct Labour charges			=	Rs.	140.00
Add for hidden cost of labour at 50% of direct labour charges			=	Rs.	70.00
Total labour charges			=	Rs.	**210.00**

Hourly use rate of Convey mucker (A+B+C+D) = Rs. **1,325.75**

Say Rupees = 1,326 / hr.

7 *Locomotive battery 3 Tonnes*

A.	Depreciation charges					
	a. Total capital cost of locomotive including all taxes, freight and insurance.	= Rs. 3,000,000				
	b. Life in years	22	year			
	c. Rated Life	40,000	hour			
	d. Depreciation charge/hr	$\frac{3,000,000 \times 0.90}{40,000}$		=	Rs.	**67.50**
B.	Repairs and maintenance charges at 100 % of cost of equipment / hr			=	Rs.	**67.50**
C.	P.O.L Charges					
	a. Battery set is charged after every 5 hrs. Electric charges including other misc. charges / hr.L.S			=	Rs.	60.00
	b. Battery set					
	Cost of 2 sets of Batteries	Rs. 270,000				
	Life	6000	hr			
	Depreciation charges	$\frac{270,000 \times 0.9}{6000}$		=	Rs.	40.50
	Lubrications etc. at 25% of sub item (a) above			=	Rs.	15.00
	Sundries and Misc. supplies at 10 % of item (B)			=	Rs.	6.75
		Total		=	Rs.	**122.25**
D.	Labour charges					
	Rated life in hours / years	$\frac{40000}{22.00}$ = 1818 *(hr / yr)*	say		Rs.	1,820
	a. Operator 1 No.	$\frac{MR \times 12 \times 1}{1820 \times 1} = \frac{6000 \times 12 \times 1}{1820 \times 1}$		=	Rs.	39.56
	b. Helper 1 No.	$\frac{MR \times 12 \times 1}{1820 \times 1} = \frac{3600 \times 12 \times 1}{1820 \times 1}$		=	Rs.	23.74
	c. Foreman 1/8 Nos.	$\frac{MR \times 12 \times 1}{1820 \times 8} = \frac{7200 \times 12 \times 1}{1820 \times 8}$		=	Rs.	5.93
	d. Mechanic 1/4 Nos.	$\frac{MR \times 12 \times 1}{1820 \times 4} = \frac{6000 \times 12 \times 1}{1820 \times 4}$		=	Rs.	9.89
	d. Chowkidar 1/4 Nos.	$\frac{MR \times 12 \times 1}{1820 \times 4} = \frac{4200 \times 12 \times 1}{1820 \times 4}$		=	Rs.	6.92
		Total		=	Rs.	86.04
	Add for hidden cost of labour at 50 % of Direct Labour Charges			=	Rs.	43.02
					Rs.	**129.07**
	Hourly use rate of Jack Hammer (A+B+C+D)			=	**Rs.**	**386.32**

Say Rupees = 386 /hr.

2. *Detailed Tunnel-Cost of Estimate Tunnel Boring Machine.*

Natpha-Jhakri Head Race Tunnel 11.15 meter (36 ft 8 in) diameter unlined, 27.3 km long, *quartzite, gneiss's- schist* and gneiss's, which are intruded by amphibolites, granite and pegmatite, medium hard theoretical rate of advance for 4 different types of machine are as follow:

M-1. **15.24 m (50 feet) per hour 5400 H.P**
M-2. **3.81 m (12.5 feet) per hour 1350 H.P**
M-3. **1.524 m (5 feet) per hour 540 H.P**
M-4. **0.305 m (1 foot) per hour 108 H.P**

The abstract of cost given is based on the rates provided in *dissertation report* (1973), which have been increased by 700% to take into account the cost of inflation. Interest 7% compounded annually, yielding $(1+0.07)^{29}$ equal to 7 times increase for equipment, but for labor charges adopted for relevant in India condition.

A. Labor (assumed 6 day-work per week, three shifts per day). (20)-p.112

No.	Trade	Number *(per shift)*	Rate in Rs. *(per hour)*	Rate in Rs. *(per month)*	Total in Rs. *(per shift/day)*
1.	Machine crew	4.00	45.00	10,800	1440.00
2.	Motormen (conveyor personnel)	3.00	25.00	6,000	600.00
3.	Brakemen (conveyor personnel)	3.00	25.00	6,000	600.00
4.	Dumpmen (conveyor personnel)	1.00	25.00	6,000	200.00
5.	Track Operator	1.00	22.50	5,400	180.00
6.	Track Crew	3.00	20.00	4,800	480.00
7.	Electrical Foreman	1.00	30.00	7,200	240.00
8.	Electricians	2.00	22.50	5,400	360.00
9.	Compressor Operator	1.00	20.00	4,800	160.00
10.	Warehouseman	1.00	20.00	4,800	160.00
11.	Warehouseman helper	1.00	15.00	3,600	120.00
12.	Carpenter (1/3)	0.33	20.00	4,800	53.33
13.	Mechanic Heavy-duty	1.00	30.00	7,200	240.00
14.	Labor crew	1.00	15.00	3,600	120.00
15.	Truck driver	1.00	22.50	5,400	180.00
16.	Walker	1.00	17.50	4,200	140.00
17.	Timekeeper	1.00	17.50	4,200	140.00
18.	Officeman	1.00	17.50	4,200	140.00
19.	Bookeeper (2/3)	0.67	17.50	4,200	93.33
20.	Superintendent (1/3)	0.33	45.00	10,800	120.00
21.	First Aid man (1/6)	0.17	17.50	4,200	23.33
	Totals	28.50			5790.00

Rate of advance per shift : (0.60 uitlization factor assume - Tasmania machine utilization was 0.63).

No.	*Drilling cap.of machine (m/hr)*	*Meter per shift*	*Rupees, in cu.meter*
1.	15.240	73.152	3.89
2.	3.810	18.288	15.56
3.	1.524	7.315	38.91
4.	0.305	1.463	194.55

B. Underground Equipment.

No.	*Equipment*	*Meter per hour*	*Rupees*	*Rupees /cu.meter*
1.	Conveyor, Rs.6500 /m' for 1/2 tunneled		88,725,000.00	
2.	Tunneling Machine Cost			
	Machine No.1 (Rs.8400 lakhs)	15.240	1,386,000,000.00	
	Machine No.2 (Rs.2887.5 lakhs)	3.810	476,437,500.00	(plus 65% import duty)
	Machine No.3 (Rs.1312.5 lakhs)	1.524	216,562,500.00	
	Machine No.4 (Rs.1050 lakhs)	0.305	173,250,000.00	
3.	Compressors, 3600 standard cubic foot per minute @ 40 pounds per square inch gage (3600 standard cu.ft per minute x 12 horsepower per 100cfm x Rs.43,750 per horsepower)		18,900,000.00	
4.	In - line ventilation fans		2,940,000.00	
5.	Water Pumps		700,000.00	
	Totals :			
	Machine No.1		1,497,265,000.00	**561.70**
	Machine No.2		587,702,500.00	**220.48**
	Machine No.3		327,827,500.00	**122.99**
	Machine No.4		284,515,000.00	**106.74**

C. Expendible Materials

No.	*Material*	*Rupees per linear meter*	*Rupees per cu.m*
1.	**Cutters:** ($100/ft')	(plus 65% import duty)	
	Supply and Maintenance	**27,066.93**	**277.21**
2.	Pipe :		
	Water 2 inchies	780.84	8.00
	Air 6 inchies	2,250.66	23.05
	Ventilation 30 inchies.	11,827.43	121.13
3.	Electrical :		
	Power Cable	43,635.17	446.90
	Lighting Cable	3,146.33	32.22
			631.30
4.	Power Transformers		
	(1230 amperes x 4.4 kilovolt = 5412 KVA), 3 KVA per Rs 31,500/-	56,826,000.00	
5.	Outdoor oil circuit breakers		
	5 KVA per Rs. 96,250 x 1/3 size effect.	243,089,000.00	
6.	3 Ø 4160 Volt trafo 225 KVA / Rs.225,000	37,884,000.00	
7.	Motor Control	7,700,000.00	
	Total Expendable Material :	**345,499,000.00**	**129.62**

D. Power

No.	Horsepower Rs.2,- / horsepower hour (Rs.2,- per kilowatt hour)	Power (Horse Power)			
		M-1	M-2	M-3	M-4
1.	Conveyor (0.025 HP per linear foot)	1120	1120	1120	1120
2.	Tunneling Machine	5400.00	1350.00	540.00	108.00
3.	Compressors 3600 cfm, (12 hp per 100 cfm)	432.00	432.00	432.00	432.00
		6951.59	**2901.59**	**2091.59**	**1659.59**

No.	Meter per hour	Rupess per cubic meter			
1.	15.24m/hr (50 ft./hr)	**12.46**			
2.	3.81m/hr (12.5 ft./hr)		**20.80**		
3.	1.52m/hr (5 ft./hr)			**37.48**	
4.	0.30m/hr (1 ft./hr)				**148.71**

E. Miscellaneous

No.	Miscellaneous	Rupees	Rupees per meter length	Rupees per cu.m
1.	Machine set up	7,000,000.00		2.626
2.	Machine Removal	7,000,000.00		2.626
3.	Pump	1,050,000.00		0.394
4.	Machine maintenance		12,631.23	129.365
5.	Conveyor maintenance		6,889.76	70.563
6.	Dewatering (low) 100 - 500 gallon /min.pipe		6,430.45	65.859
7.	Steel supports		10,219.82	104.668
8.	Foot Blocks		160.76	1.646
9.	Timber lagging		16,076.12	164.647
10.	Appurtenant Facilities & tunnel inlet&outlet.		9,760.50	99.964
	sub-total			**642.359**

F. Insurance

No.	Original Cost (Rupees)	(20 % of Original Cost)/cu.m			
1.	Machine No.1 (Rs.8400 lakhs)	63.03			
2.	Machine No.2 (Rs.2887.5 lakhs)		21.67		
3.	Machine No.3 (Rs.1312.5 lakhs)			9.85	
4.	Machine No.4 (Rs.1050 lakhs)				7.88

G. Depreciation

No.	Type of Machines	Machine Cost at site (Rs.)	Life of machine		Depreciation charge/hr/m^3
			(in Hours)	*(in Years)*	
1.	Machine No.1 (50 ft/hr)	1,386,000,000	12000	10	12.68
2.	Machine No.2 (12.5 ft/hr)	476,437,500	12000	10	1.09
3.	Machine No.3 (5 ft/hr)	216,562,500	12000	10	0.20
4.	Machine No.4 (1 ft/hr)	173,250,000	12000	10	0.03

H. Summary of Tunneling Cost Estimate - Tunnel Boring Machine.

No.	Item of Cost	Cost in Rupees /cu.m at advance rate of			
		15.24 m./hr	*3.81 m./hr*	*1.524m./hr*	*0.305m./hr*
1.	Labour	3.89	15.56	38.91	194.55
2.	Underground equipment.	561.70	220.48	122.99	106.74
3.	Cutters	277.21	277.21	277.21	277.21
4.	Other expendable materials	760.92	760.92	760.92	760.92
5.	Power	12.46	20.80	37.48	148.71
6.	Miscellaneous items	642.36	642.36	642.36	642.36
7.	Insurance Spareparts (20% of original TBM)	63.03	21.67	9.85	7.88
8.	Depreciation of machines	12.68	1.09	0.20	0.03
	Sub - total	2334.25	1960.09	1889.91	2138.40
	Add for construction and maintenance of haul road at 4 % of total charges.	93.37	78.40	75.60	85.54
	Add for electric energy charges at 2 % of total charges	46.68	39.20	37.80	42.77
	Prime cost	2474.30	2077.69	2003.31	2266.70
	Add overhead charges and contractor's profit at 20 % of prime cost.	494.86	415.54	400.66	453.34
	Total	**2969.16**	**2493.23**	**2403.97**	**2720.04**

I. TOTAL COST

No.	Drilling capacity of machine *(meter/hour)*	Cost *(Rs/m^3)*	Total Excavation (m^3) *(plus overbreak 2.5%)*	*Total Cost* *(Rs.crores)*
M-1.	15.240	2969.16	2,732,211	811.24
M-2.	3.810	2493.23	2,732,211	681.20
M-3.	**1.524**	**2403.97**	2,732,211	**656.82**
M-4.	0.305	2720.04	2,732,211	743.17

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