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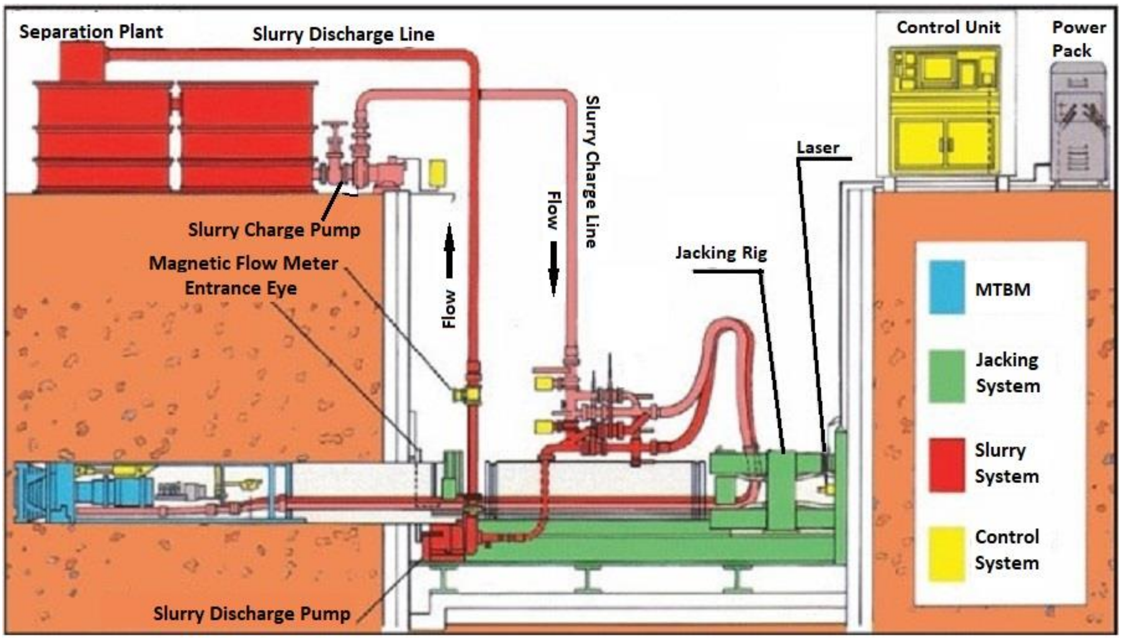
GUIDELINES ON PIPE PUSHING BY MICROTUNNELING TECHNIQUE FOR RAILWAY BRIDGES



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GUIDELINES ON PIPE PUSHING BY MICROTUNNELING TECHNIQUE FOR RAILWAY BRIDGES

1. Introduction

Microtunneling is an effective method of installing pipelines beneath highways, railroads, runways, harbors, rivers and environmentally sensitive areas especially where maze of underground utility lines already exist.

Microtunneling is a trenchless construction method for installing pipelines that uses a remotely controlled Microtunneling Boring Machine (MTBM) combined with the pipe jack and bore method to directly install pipes underground in a single pass. This process avoids the need to have a long stretch of open trench.

These guidelines deal with the requirements for pipe pushing by microtunneling as well as providing information regarding the minimum requirements or limiting conditions for project execution and is recommendatory in nature.

2. Applicability, Advantages & Disadvantages of Microtunneling

Microtunneling is a useful method for replacement/insertion of pipes with greater surcharge height, when additional openings are required or when the pipes are to be laid in yards, etc. In such situation, executing the work by relieving girder or by conventional method of box pushing is either infeasible, cumbersome or time consuming. As it doesn't require any traffic block, leading to reduced fuel consumption & travel, no time loss as required in open cut method. MTBM work has been successfully carried out over IR in Bhubaneswar Yard, Igatpuri Yard, Igatpuri-Kasara sections and other sites.

Microtunneling can be used advantageously in following site conditions:

i. Where conventional method requires deep excavation.

ii. In case of high ground water table conditions

iii. In case of contaminated ground conditions

iv. In case of traffic disruptions are costly or unaffordable

v. For reduced environment damage, reduced cost of construction, less noise & less vibration

However, followings are limitations in Microtunneling:

i. Limited options if unexpected conditions encountered resulting in machine stoppage

ii. Change of strata is encountered resulting into requirement of different type of MTBM

iii. The cost of preparatory work and making construction pit is relatively high i.e. there is high fixed cost.

iv. Extra caution will be required while operating below track to prevent subsidence of the formation.

3. Features of Microtunneling

Microtunneling is a trenchless construction method for installing pipelines with following key attributes:

i. Continuous pressure is exerted at the excavation face to balance groundwater and earth pressures

ii. Remote control is used in operating the Micro tunnel boring machine (Shields)

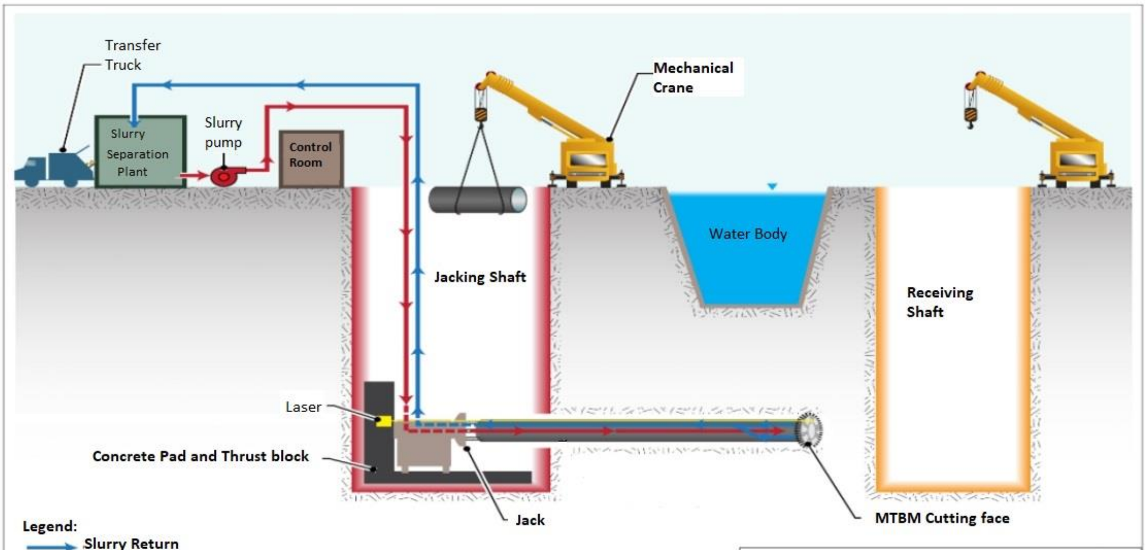
iii. Automated spoil removal system

iv. Pipe jacking is used to install pipelines

v. Guidance system to guide and tunnel excavation

vi. Remote control system to operate the shield and other paraphernalia equipment.

4. Procedures and salient steps in Microtunneling



Profile View of Pipe Pushing by Microtunneling Technique

4.1. The procedure used in Microtunneling, with slurry shield machine, will typically comprise of following steps:

i. The MTBM and jacking frame are set up in a shaft at the required depth.

ii. After attaching the slurry line and control cables, the MTBM is pushed into the earth by hydraulic jacks mounted and aligned in the jacking shaft.

iii. The jacks are then retracted and the slurry lines and control cables are disconnected.

iv. A product pipe or casing is lowered into the shaft and inserted between the jacking frame and the MTBM or previously jacked pipe.

v. Slurry lines, power and control cable connections are again made, and the pipe and MTBM are advanced for another drive stroke.

vi. This process is repeated until the MTBM reaches the reception shaft.

vii. Upon drive completion, the MTBM & trailing equipment are retrieved and all equipment removed from the pipeline.

4.2. Detailed procedure in any Microtunneling operation is as follows:

i. After establishing reference points for line and level at each shaft, the shafts are prepared for Microtunneling by constructing a concrete head wall and an entrance eye with a specially designed seal. The jacking frame is then installed in shaft and a rear thrust wall constructed to transfer the load from the rig on to the shaft wall at the required depth.

ii. After installation of the jacking frame, the control container and the other surface equipment is set up in pre-determined arrangement, depending on site location and access.

iii. Pipes, pumps, hydraulic lines and cables are installed and a bracket for a laser fixed to the shaft wall, away as possible from the jacking zone. The laser is then set to line, level and the gradient for the drive entered. The gradient is checked across the shaft.

iv. The MTBM is lowered into the shaft and set up in the jacking rig, connected to the slurry system, power cable and the control systems. All functions are checked and ready to commence the drive.

v. The operator commences the drive by pushing the head through the seal against the shaft wall and starts cutting through the concrete entrance eye. The cutting operation should be very carefully monitored. The slurry system is not operated until the head of the machine start to bury in the ground outside the shaft. A thrust ring is supplied with the system to transfer the jacking load to the pipes. Excavation then proceeds as the head is jacked forward.

vi. A laser is utilized to provide guidance to the operator of the TBM (Tunnel Boring Machine). Lasers utilized have a pinpoint resolution up to 1000 m.

vii. The laser is set to line and level/slope according to the survey.

viii. At the start of each shaft, a “laser check” is carried out to ensure that no horizontal/vertical movement to the laser accrued. Results of the laser check are then documented.

ix. After the satisfaction of TBM operator with the laser check, normal micro-tunneling operation may continue.

x. To reduce the friction on the whole micro tunnel drive, bentonite is pumped through injection points placed in the tail of the cutter head. An annulus of bentonite is maintained along the length of the pipeline using a special seal at the exit point from the shaft.

xi. Excavated material is removed from the settlement tank by means of an excavator, fitted with a hydraulic grab. The settlement tank is emptied once or twice each drive.

5. Terminology and General Description

5.1. Microtunneling

Microtunneling is a process of accurately excavating, non-man entry tunnels for installing underground pipelines, using laser guided remote controlled mini shields (MTBM) of diameters as small as 250 mm. The Microtunneling permits accurate monitoring and adjusting of the alignment and level (either manually or automatically) as the excavation proceeds.

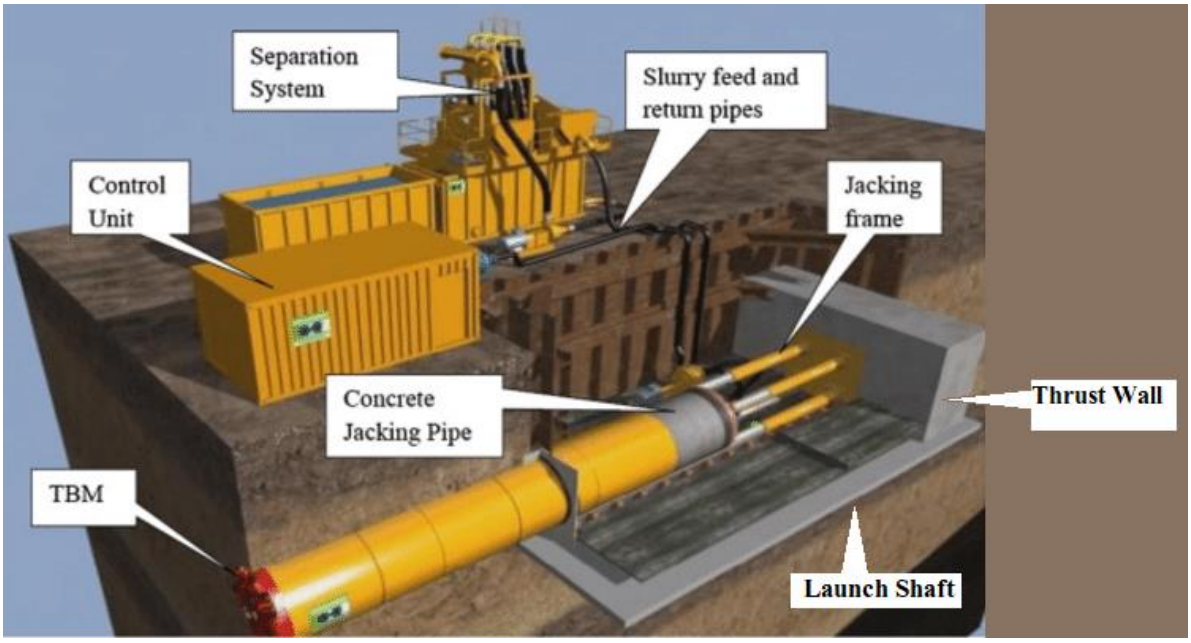
5.2. Pipe jacking

It is a process of lining a tunnel bore formed by a shield or other means by pushing especially designed jacking pipes (reinforced concrete or other pipes) into the tunnel bore, from a shaft (known as jacking shaft) to another shaft (known as receiving shaft).

5.3. Microtunneling and Pipe jacking

It is an art of accurately installing smaller diameter pipelines (usually 250 mm diameter and above), without digging up of ground surface, using a laser guided remote controlled mini shields for tunnel boring and pipe jacking technique for lining the bore with the product pipe.

Continuous pressure is exerted at the excavation face to balance groundwater and earth pressures. Essentially, the microtunneling process is a cyclic pipe jacking operation. Microtunneling boring machines are very similar to Tunnel Boring Machines (TBM) but on a smaller scale. These machines generally vary from 0.25m to 1.5m but smaller and larger machines exist.



5.4. Microtunnel Boring Machine

It is mechanized, steerable mini boring machine (shield) equipped with suitable cutter head in front to excavate small diameter tunnels under controlled conditions in which the tunnel face and ground water pressure are continuously balanced as the shield excavates and moves forward. The operation and steering of the shield are remotely controlled with the aid of laser and/or CCTV system.

The line and level control shall be achieved by a laser beam transmitted from the jacking shaft to the target mounted in the tunneling machine. The design of the machine shall ensure no rotation or rolling during installation.

It is a horizontal boring machine consisting of three portions:

i. The first portion consists of a front rotating diamond cutter. The cutting wheel is equipped with carbide tipped tools to cut the entire face of the tunnel. Excavated material passes through openings in the cutting wheel into the crushing/mixing chamber.

ii. The second portion is non-rotating portion and consists of inlet and outlet for fixing of water hose pipes, laser guiding machine and motors for rotating the cutter head.

iii. The third portion consists of hydraulic pump, hydraulic power pack, electrical panel board and laser guiding target system including a camera.

The MTBM itself is a 2.5m to 3m long steel cylinder in which is housed a powerful electric motor to turn cutting spokes at the face of the machine and in this way the soil is cut in front of the machine. The steering system of the MTBM should be able to steer in all directions. Also in the MTBM is an articulated joint, which can move approx. 3 degrees and which are actuated by three powerful hydraulic jacks. The steering head of the

MTBM is operated in this way by the operator from a control cabin via a computerized console.

5.5. Automated spoil removal system

This system conveys the excavated spoil from the tunnel face to the ground surface for disposal. The spoil removal rate and the speed of the shield are fully or semi-automatically controlled in such a way to achieve minimal heave or settlement. There are three systems available for the conveyance of the spoil and they are slurry system, auger system and vacuum system.

5.6. Jacking System

The jacking system comprise high thrust hydraulic jacks mounted in a jacking frame capable of exerting the required jacking force against a purpose-built thrust wall to push the pipe and the shield forward through the ground. Anticipated jacking force must be evaluated in terms of the baseline and anticipated ground conditions to ensure that the pipe and the thrust reaction wall are designed to safely resist the jacking forces and that the jacking system has adequate capacity. The jacking force is transferred evenly to the jacking pipe through a push ring connected to the pipe. Jacking frame is installed between the jacking assembly and jacking pipe.

The jacking system must have the capability to push the MTBM and pipe through the ground in a controlled manner. The system must apply a uniform force around the pipe with the use of a push ring specifically designed for the pipe being used. The jacking capacity of the system, including Intermediate Jacking Stations (IJSs), must be greater than the anticipated jacking forces, with a reasonable factor of safety.

5.7. Guidance System

The guidance system comprises a laser beam device or a theodolite with laser beam attachment. The device is installed in the jacking shaft and the beam is set to the desired level, gradient and alignment.

Some machines have photo sensitive cells on the target panel located at the rear of the shield which converts the laser position into digital data. The data are then electronically transmitted to the operator’s control panel where digital readout of the location can be made. Some modern shields have built-in capabilities to use the digital data and automatically make necessary steering adjustments to guide the machine to the true alignment and level.

The laser torch or theodolite shall be firmly supported in the jacking pit so that it is independent of any movement that may take place during the microtunneling operation.

5.8. Supplementary systems

The supplementary system required for microtunneling and pipe jacking operation shall include Muck disposal system, Pipe lubrication system, Grouting system, Guide rails, Entrance and Exit installations.

5.9. Jacking shaft (Jacking Pit)

Jacking Shaft is an important temporary structure from where jacking operation is performed. The shaft is usually rectangular or circular in shape and built using liner plates, sheet piles or timber shoring. The size of the shaft shall be such that it is capable of accommodating the jacking equipment and the MTBM, jacking pipe and other paraphernalia to enable construction of manhole or chamber as needed. It is usually constructed at locations where permanent manholes are to be built. The requirement for jacking shaft shall take full cognizance of the available working space and intended equipment. Pipes of up to 3.0 meters length can be launched from shafts of 5.0 meters long or more depending on the pipe diameter (from thrust wall to front wall).

5.10. Receiving shaft (Receiving pit)

A purpose-built temporary structure to receive and remove the MTBM after its completion of a tunnel drive. The shaft is also rectangular or circular in shape and smaller than the jacking shaft. The size shall be sufficient enough to accommodate the tunneling shield when it emerges into shaft after completion of a tunnel drive or construction of manhole or chamber as needed.

5.11. Footprint

The footprint of a micro tunnel drive shall be taken as the net area occupied by the jacking or receiving shafts. The size of the footprint depends on many factors including the microtunneling system and the length of jacking pipe used. The footprint requirement shall be an important factor, especially in congested and narrow roads when selecting the microtunneling system for a project.

The Engineer shall take into consideration the space constraints and restrictions along the pipeline route for location of shafts and shall ensure that the microtunneling system selected for use in such sites shall require absolutely minimum space for the footprint.

5.12. Thrust wall

Thrust wall is a temporary concrete or steel structure built within the jacking shaft to transfer the jacking force to the ground during jacking operation. The jacking shafts may often have more than a single thrust wall and each thrust wall shall be perpendicular to the pipeline to be jacked. The thrust walls shall be in good contact with the soils behind so that wall can transmit the jacking force effectively to the ground without affecting the shoring system. The thrust wall, the rear of the jacking rig being suitably shaped to bear against it, provides the reaction for the pipe thrusting forces.

All the affected thrust wall shall be demolished fully or partly after completion of jacking operation involving in that wall.

5.13. Entrance Ring

A steel flange fitted with a rubber seal (a 10mm to 20mm thick circular rubber gasket whose outside diameter is same as that of the steel flange and the inside diameter is smaller than that of the jacking pipe) installed perpendicular to the pipeline at the entrance. The purpose of the rubber seal to prevent the slurry or ground water from entering into the shaft through the pipe entrance.

5.14. Exit Ring

This is similar to the entrance ring except that the internal diameter of the rubber seal is much smaller than that of the jacking pipe and is installed to prevent the slurry or ground water from escaping the tunneling machine when it emerges at the receiving shaft.

5.15. Guide Rails (Jacking Table or Frame)

To facilitate placing of the microtunneling machine and pipes in the jacking shaft, a set of guide rails are installed in position on the base of the shaft. The guide rail assembly (also known as jacking table/frame) shall be carefully set up in the shaft to correct alignment and gradient so that the pipe when placed on it stays in line with the square to the pipeline alignment. The guide rail assembly shall be independent of the thrust wall so that it is not disturbed due to jacking force exerted onto the thrust wall.

5.16. Thrust Pressure Plate

The thrust pressure plate is usually a 50mm or 100mm thick steel plate installed between the jacks assembly and the thrust wall. The pressure plate enables the concentrated jacking load from the jacks to be transmitted evenly to the thrust wall.

5.17. Intermediate Jacking Station

For longer distance jacking, intermediate jacking stations, comprising a telescopic type jacking pipe assembly (usually made of steel), are used. A set of inter jacks and push ring are installed around the inner side of the female pipe of the telescopic pipe assembly. The intermediate jacking pipe assembly shall be installed at appropriate point and jacked-in along with the other jacking pipes.

5.18. Cutter head

It is usually a disc shaped wheel mounted on the face of the microtunneling machine (shield) and is driven by hydraulic or electrical motor, located within the machine. The excavation capabilities of a microtunneling machine depends very much on the type of cutter head used, its speed of rotation and average & peak torque etc.

Different types of cutter head configuration are used in microtunneling machines to suit the type and nature of the ground through which tunneling is to be carried out. For example in soft ground tunneling, the cutter head shall have bits arranged in such a way to cleave and guide the soil into a chamber behind the cutter head through the openings provided in the cutter wheel.

In the case of rock or hard ground tunneling the cutter head shall be equipped with suitable bits, roller bits or disc cutters for effective transfer of cutting energy to rock. The cutter head shall be configured appropriately considering geotechnical parameters such as compressive strength, tensile strength, elasticity, abrasivity, etc, of the material to be excavated. The tunneling machine shall be equipped with a crushing chamber behind the cutter head with powerful crusher to crush the excavated rocks into smaller pieces. Moreover, the machine shall be capable of exerting a large thrust force/torque on the tunnel face to facilitate excavation of rock. The speed of rotation, torque, bit arrangement (its structural and mechanical characteristic to withstand rock excavation for longer drive) of the cutter head and the thrust force the tunneling machine is capable of exerting on to the rock face are important features to consider when selecting machines for tunneling in rock.

5.19. Jacking Ring

Jacking ring is a purpose made structural fitting which shall be installed between the jacking assembly and the jacking pipe to transfer the point loads from the individual jacks into evenly distributed jacking force to the pipes being jacked. The ring shall be fabricated and machined, if necessary, so that it fits exactly onto end of the jacking pipe. The jacking rig rest on the floor of the launch shaft and serves as a cradle for the launch of the machine and the tunnel lining pipes. The jacking rig has integral ratchet device to allow the pushing of long pipes up to 3.0m length with the short stroke cylinders.

5.20. Slurry Separation System

The slurry separation equipment tank, consists of two containers, kept at different levels are situated on the surface. The excavated material is removed from the tunnel face and pumped out by the slurry pump system in slurry separation equipment tank. Slurry is deposited in one tank and over flow water after in other. The water is then re-used. The spoil removal rate and the speed of the shield are fully or semi-automatically controlled in such a way to achieve minimal heave or settlement.

5.21. Material conveyance

A centrifugal pump located next to the settling tank on the surface pressurizes the feed water to the crushing/mixing chamber nozzles. The excavated material is mixed with the feed water to form slurry, which is pumped out by the slurry pump located in the launch shaft.

The pumps have variable speed controls to adapt to varying ground conditions and balance flow rates.

A bypass valves system within the cutting head enables washing out of the slurry lines and partial recirculation. These valves also isolate the cutting head whilst the pipeline is broken to insert a new sleeve pipe. Thus, face support can be maintained whilst the slurry material transport system is disconnected when putting in a new jacking pipe.

The slurry is pumped into a settling tank on the surface from which the feed water is drawn. Excavated material is removed at intervals from the settling tank as required.

5.22. Control Cabin

From control cabin, the operator controls the MTBM. Operator steers the machine using data from a laser beam, which impinges on to a target inside the MTBM and from other instrumentation including pitch and roll inclinometers. From the control cabin, operator can see MTBM speed, earth pressure, slurry flow rate, valve position, head torque and more so operator can remain on complete control of the machine at all times.

5.23. Flushing medium

Lubricant used in Microtunneling should be designed to accomplish the following tasks:

i. Reduce friction between pipe and excavated ground as the pipe is jacked forwarded.

ii. Maintain the annular space between the pipe and the ground.

iii. Form a filter cake to limit the amount of fluid loss into the ground

iv. Maintain its composition when pumped under pressure into the annular space.

v. Maintain its composition and properties during long periods of inactivity and

vi. Resist the loss of integrity when exposed to chemical contamination.

Various definitions are given in Annexure I.

6. Methods

6.1. Microtunneling involves civil works, setup of machine and jacking operation. There are two methods which are normally used in Microtunneling. They are:

6.1.1. Microtunneling with auger spoil removal-

One or two-phase steerable jacking of pipes with simultaneous excavation of the working face by means of a cutting head and continuous transport of spoil using a conveyer (auger).

6.1.2. Microtunneling with hydraulic spoil removal (slurry system)-

One or two-phase steerable jacking pipes with simultaneous full-face excavation of the mechanically- or fluid- balanced working face by means of a cutting head and continuous indirect transport of the spoil using a liquid flushing medium (also called slurry shield microtunneling)

These methods are used depending upon the ground condition at the face of the cutter head. Slurry system shall be adopted for higher groundwater pressures and unstable ground condition. Auger method should be used for small diameter pipes or casing as more power is required for larger pipes. Use of microtunneling method may be decided based on Fig. 1 and Table 1.

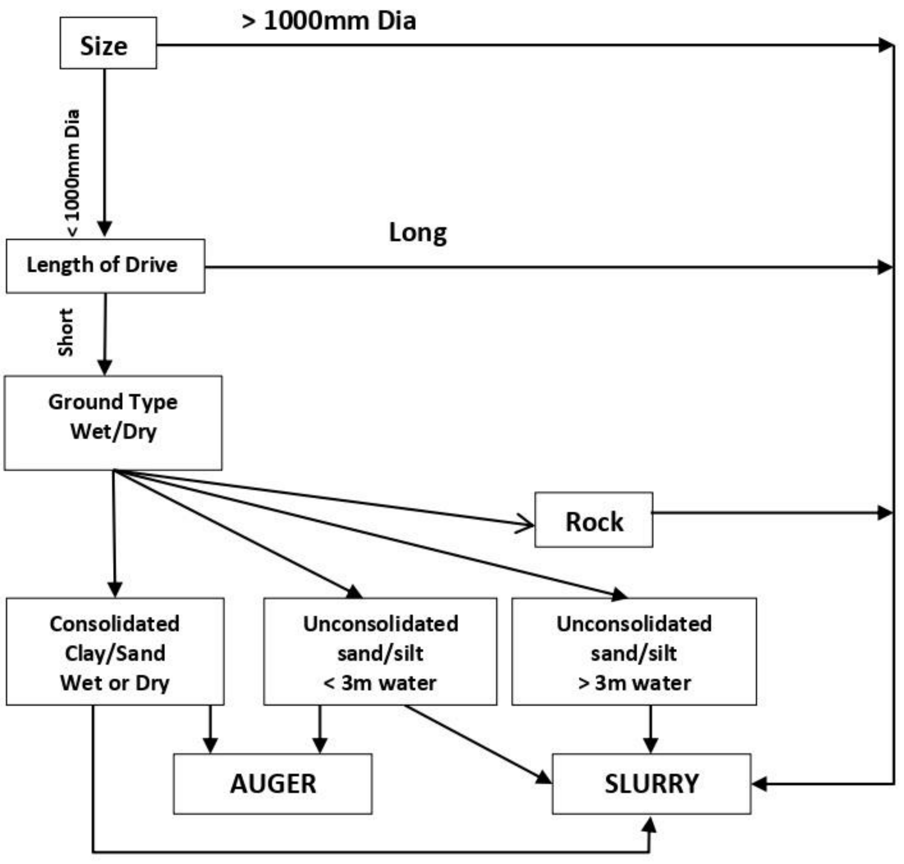


Fig 1-Slurry type and Auger type MTBMs

Table 1: Microtunneling capabilities for Different Ground Conditions

Ground Condition	Microtunneling	
	Slurry	**Auger**
Soft to very soft clays, silts, and organic deposits	Y	M
Medium to very stiff clays and silts	Y	Y
Hard clays and highly weathered shales	Y	Y
Very loose to loose sands below water table	Y	N
Very loose to loose sands above water table	Y	Y
Medium to dense sands below water table	Y	N
Medium to dense sands above water table	Y	Y
Gravels and cobbles less than 150mm in diameter	Y	Y
Soils with significant cobbles, boulders and objects larger than 150mm in diameter	M	M
Weathered rocks, marls, chalks, and firmly cemented soils	Y	Y
Slightly weathered to unweathered rocks	M	N
Y- Yes. Generally suitable for experience contractor using appropriate equipment.		
N- No. Substantial problems; generally unsuitable or not intended for these conditions.		
M- Marginal. Difficulties may occur and some modifications of equipment or procedure may be required.		

6.2. In case of auger spoil removal, the size of the particle should not exceed one–third of the diameter of the spiral conveyer. Where ground collapsing is probable the cutting head should work in the protection of the shield skin in order to prevent uncontrolled soil collapses.

6.3. In auger type spoil remover when the working face is pressurized with compressed air then a greater depth of cover must be chosen to prevent blow out.

6.4. In case of hydraulic spoil remover the pumped solid–fluid mixture (slurry) must be separated in order, on one hand to make the flushing medium available to the conveying circuit and again on other hand to prepare the solids for disposal.

6.5. A separate shield skin with a suitable external diameter and a corresponding cutting head must be used for pipe size required for the project.

6.6. High pressure jet system should be provided in order to prevent possible blocking or clogging of the boring tools which could lead to substantial reduction of the effectiveness of the excavation tools as well as jacking performance when boring in cohesive soil or in disturbed or fault zones with cohesive soils in rocks.

6.7. In case of hydraulic spoil removal, the pressure of the hydraulic circuit should always be slightly greater than the natural ground water pressure. If the pressure is lower, this might lead to liquefaction of the soil and can cause sudden sink.

7. Microtunneling Design Elements

7.1. Earth Loads on Pipe (Important consideration)

Selection of the appropriate pipe class or stiffness requires a reasonably conservative estimate of earth loads acting on the pipe. Computation of earth load is significantly different for pipe tunneled through undisturbed ground and for pipe within an excavation. Pipe installed by microtunneling experiences lower earth loads than pipe installed in open trenches, because of the ground’s natural arching ability.

Earth loads on pipe installed by microtunneling are proportional to the diameter of the pipe and effective unit weight of the ground. Earth loads are inversely proportional to ground stiffness.

- For pipe installed in medium stiff to hard clay, or in very dense sand, the earth loads acting on the pipe are typically less than the diameter of the pipe multiplied by the effective unit weight of the ground.

- For pipe installed in soft clay or in loose to medium sand, the earth loads acting on the pipe may approach two to three times the diameter of the pipe multiplied by the effective unit weight of the ground.

- Earth loads on microtunneled pipe in stable rock and hard clay are negligible.

- Total overburden stresses should not be used to calculate earth loads on pipes except for relatively shallow installations in soft, squeezing clays and in loose to very loose sands.

7.2. Evaluation of settlement risks

The risk of ground movements (both vertical and horizontal) and the potential effect on the critical features should be evaluated. An acceptable approach is to identify sensitive and critical utilities, roadways, railroads, foundations, and other facilities that may be at risk from the microtunneling and shaft construction activities. It is a good idea to establish recommended maximum allowable settlements for critical facilities in coordination with facility owners.

The steps for settlement risks include the following

- Identify facilities at risk for settlement.
- Establish recommended maximum allowable settlements for critical features through consultation with the facility owner.
- Evaluate potential settlements at each feature.
- Compare estimated settlements against recommended maximum allowable settlements for each feature, and develop mitigation measures to reduce effects on significant structures, if necessary.
- Develop a settlement instrumentation and monitoring plan for the project, and ensure that the plan is implemented during construction.
- Coordinate with permitting agencies and owners of critical facilities, a critical step in successful implementation of a proactive program to avoid damages that may occur as a result of microtunneling and shaft construction.

8. Planning of pipe pushing by Microtunneling

8.1. In the planning phase of the project, a preliminary geotechnical investigation should be performed to identify the general subsurface conditions and any special subsurface conditions.

8.2. The sources of additional information include geologic and topographic maps, aerial photographs, soil survey reports, construction case histories, professional papers about the area, historical documents concerning prior site usage, and discussions with local building officials and local contractors.

8.3. To provide insight into anticipated subsurface conditions, potential future conflicts, and other potential problems, an investigation should be undertaken into the history of the area proposed for Microtunneling operations, as well as current zoning and plans for future development.

8.4. Underground utilities and other facilities along or crossing the Microtunnel alignment must be identified during the planning process.

8.5. Non-removable obstacles cannot be overcome and can only be avoided by rerouting the planed line alignment. It is therefore necessary in the planning stage to obtain accurate information of their positions.

8.6. Catchment area and a design discharge should be calculated to determine the size of the pipe and size of the receiving pit.

8.7. The ground levels on both ends of the tunnel including the bed levels of existing drains in upstream and downstream should be taken and based on these, pipe bed gradient should be decided.

8.8. The rock cutting heads should be considered and used in those cases where no exploration of the sub soil can take place.

8.9. Mixed-face conditions are to be avoided, if possible. If mixed-face conditions cannot be avoided, should be documented. If a mixed-face condition is known to exist along the alignment, contingency plans should be developed by the engineer during the design phase and before construction.

8.10. Dewatering in the immediate vicinity of active Microtunneling operations should be avoided, since it can result in loss of drilling fluid & slurry in the face of the MTBM and increased friction on the pipe, & higher jacking forces.

8.11. Historic buildings and environmentally sensitive areas usually require evaluation on a case to case basis to ensure their protection.

8.12. In case of contaminated ground or ground water, determination of the nature and extent of the contaminants must be undertaken during the site investigation. Even if contaminants are not identified during the planning phase, the site investigation should still look for and test for contaminants.

8.13. Microtunneling can be advantageous when contaminated materials are encountered. Sources of information regarding the potential for contamination include health department records; fire, planning, and building departments; and local or regional agencies responsible for pollution control or water quality.

8.14. Excavation of the jacking and receiving shafts before Microtunneling is useful in conforming geotechnical subsurface conditions before jacking pipe.

8.15. All shafts need crane access to build the shaft and then position and remove MTBM, pipe material and support equipment.

8.16. The choice of cutting head depends on the ease of excavation of the in situ soil including the presence of boulders and cobbles.

8.17. The cutter wheel must be capable of bidirectional drive. Antiroll fins or grippers may also be installed, but not as the primary method of rotation control.

8.18. A larger diameter MTBMs generally have more power, thrust, and torque for processing rocks and buried objects in the tunnel horizon and can achieve longer drives.

8.19. Intermediate jacking stations are typically not practical for internal diameter of less than 1m.

8.20. Shafts are typically located at changes in alignment (both horizontal and vertical), changes in the pipe diameter, and changes in geotechnical conditions.

8.21. Microtunneling drives should be located to minimize the amount of gravels, cobbles, and boulders to be encountered, if possible. If these conditions cannot be avoided, the MTBM should be operated and selected with features designed to reduce risk when excavating through cobbly and bouldery ground. If anticipated cobble and boulder size and number are expected to obstruct the MTBM, allowance for obstruction removal or MTBM rescue should be provided in the bid documents.

8.22. In situations where numerous cobbles and/or boulders are expected, the MTBM diameter should be increased to allow easier excavation of the cobbles and/or boulders.

8.23. Joint survey should be done with OHE, S&T, Permanent-way and Electrical officials for selection of suitable alignment.

8.24. The recommended safe distance of the edge of the entry/exit eye from the outermost railway track centre will be equal to 3m plus twice the formation height plus the depth of entry/exit eye. However, this distance will depend upon the local soil conditions and has to be decided by the executive at site after taking into consideration the type of soil and provision or non-provision of any shoring etc.

8.25. A minimum cover of two pipe diameters or 2m, whichever is deeper, is needed to allow sufficient depth for the ground to arch over the new installation and for the slurry and lubrication to be confined. Evaluation and calculation of the potential settlement and heave risk should be performed to assist in the selection of the appropriate ground cover.

8.26. The Engineer should consider including, at each manhole location, an additional drop of 30mm or more plus the grade tolerance to assist in maintaining the design grade during Microtunneling construction. Over the length of project, these drops can be used to help maintain the overall grade in the pipeline.

8.27. The size for jacking and receiving pits should be decided. Suitable drawing showing the plan and the cross section including location of jacking pit, receiving pit, pipe line alignment etc. should be prepared for approval of competent authority and sanction of CRS to be obtained, if required as per extant rule.

8.28. Reinforced concrete pipe joints shall be flexible consisting of a fixed stainless steel or other elastomeric seal (rubber ring) complying with IS, such approved material shall be incorporated in each pipe joint, including joints between pipes and interjacks/MTBM. The design of the seal shall be commensurate with the detailing of the pipe joint. Seals may be fitted either at the place of manufacture or on site prior to placing of the pipe below ground. In either case, the seals shall be fitted in accordance with the manufacturer's instructions. Seals shall be inspected for damage by the surface crew immediately prior to pipe use and any damaged seals are replaced. Pipe seals shall be suitably lubricated with a soap solution or other such compound in the pit bottom immediately prior to closing the joint with the jacking frame.

8.29. When a project needs multiple sizes of pipe installed, organization might choose to mobilize one MTBM and then upsize it to complete the other diameter.

8.30. The pipes to be used should be inspected before jacking for defects.

8.31. Generally, minimum staging area should be 256m^2 for jacking shafts and 146m^2 for receiving shafts. This working space includes the shaft footprint. Working space can be reduced by storing jacking pipe in other areas and using gantry cranes.

8.32. Crossing Approaches: Generally, the angle of crossing between the pipeline and centre line of the facility (roads, railways etc.) to be crossed should be 90 degree. A straight line approach (no side bends at crossings) on at least one side or sufficient rights–of–way or temporary working space to assemble and pretest (hydro test) the entire jacking pipe string prior to installation. The facility being crossed should not be in a deep "cut". Level, terrain or slight fill of road-bed provides desirable boring conditions.

8.33. Alignments: The layout of the bore and the final pipe alignment should fulfill the required alignment condition. Pipe jacking shall be carried out in any material encountered true to line and level. The Engineer shall provide such continuous supervision as is necessary to maintain accuracy of line and level. MTBM must be articulated in such a way as to enable controlled steering in both the vertical and horizontal direction, to a tolerance of ±3% of the MTBM diameter or 25mm, whichever is greater on grade and ±6% of MTBM diameter or 50mm, whichever is greater on line from the design grade and line. The Engineer should consider using a two-phase approach when the design grade and line tolerances must be less than mentioned before.

8.34. All safety precautions related to site, materials, electrical connections, hydraulic connections, jacking, adequate lighting, installation of gas detectors, etc. shall be ensured.

8.35. Settlement point readings will be taken on daily basis as long as jacking pipes are installed and line grouted.

8.36. Readings inside microtunnel will also be taken at every two meters so as to make sure that there is no settlement.

8.37. To prevent flooding of the shaft, normally a 6 inch submersible pump will be kept operational in driving shaft as long as the machine is tunneling and also during pipe installation.

8.38. Contingency plan on excessive ground movement, excessive water inflow shall be prepared.

8.39. The flushing medium should not cause any damage to the nearby areas due to leakage. Any damage to the highway or non-highway facility caused by escaping flushing medium shall be immediately restored by the operator.

8.40. Jacking Pipes for Microtunneling

8.41. Pipe should be designed to withstand all the forces/loads including surface load acting during construction/microtunneling during survice life for actual bedding condition and earth cushion available at site.

8.42. Pipe must be designed to resist all forces/loads and chemical attacks during transport, handling, jacking and use within the supposed lifetime for the given project. Accordingly, material of pipe shall be decided.

8.42.1. Pipes supposed to be used for jacking are designed and produced to resist all loads and damage from the construction process, including crushing of the material due to load transfer at the joint. The proof-design shall be carried out using a design procedure in common use in India.

8.42.2. All pipes shall be cast with a minimum of 3 grout holes of minimum dimension ¾″ BSP. Each hole shall have provision for taking a steel connector for lubricant injection during jacking operations; such provision being cast in.

8.42.3. Pipes shall be designed to withstand the maximum axial thrust with a factor of safety of 4 based on the full effective areas of the joint surface and the ultimate compressive strength of the pipe material.

8.42.4. The concrete shall be of minimum characteristic compressive strength of 50 MPa determined in accordance with IS 456.

8.42.5. Pipe used in Microtunneling should have the following characteristics:

- Pipe should be non-restrained
- Joints should be flexible within the wall thickness.
- Pipe should have smooth external and internal contours.

8.42.6. Any of the following defects warrants pipe rejection:

- Concentrated ridges, discoloration, excessive spot roughness and pitting.
- Insufficient or variable wall thickness.
- Pipe damage from bending crushing, stretching or other stress.
- Any other defects of manufacturing or handling.

8.42.7. Pipes shall be designed and manufactured as per applicable BIS, BS, ASTM codes.

9. In-Line Microtunneling

In-line microtunneling is used to replace an existing pipe in place.

9.1. In case of In-line Microtunneling, the new pipe must be larger than the existing pipe, with the existing pipe enveloped by the face of the MTBM. The existing pipe must be of a material that can be easily broken down and ingested into the face of the MTBM.

9.2. It may be considered when pipe bursting is impractical, when an existing pipe has insufficient required flow capacity, when there is insufficient horizontal space in the corridor, or when known objects (remnants from past construction or natural) impede the installation of new pipe at the same vertical alignment.

9.3. If a slurry Microtunneling machine is used, the existing pipe should be backfilled with a low-density, low-strength flowable fill before commencing in-line Microtunneling operations, to prevent loss of drilling fluid and slurry through the existing pipe.

9.4. The relative positions of the old existing pipe and the new in-line Microtunneling pipe are important and position are:

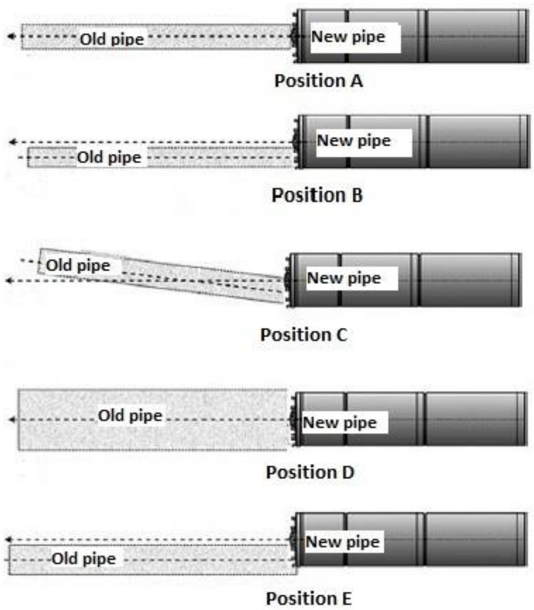


Fig 2 - In-line microtunneling and the relative position of the old and new pipe

i. Position A: The centerline of the existing pipe and the in-line Microtunnel are at the same line and grade, and the new installation is larger.

ii. Position B: The centerline of the existing pipe and the in-line Microtunnel are at the same line and grade but are offset, although the new installation is large enough to include excavation below the existing pipe.

iii. Position C: The centerline of the existing pipe and the in-line Microtunnel are along the same line but with different grades, although the new installation is large enough to include excavation of all portions of the existing pipe, from the jacking shaft to the reception shaft.

iv. Position D: The centerline of the existing pipe and the in-line Microtunnel are at the same line and grade, and the new installation is smaller than the existing pipe.

v. Position E: The centerline of the existing pipe and the in-line Microtunnel are at the same line and grade but are offset, and the new installation does not consume the entire existing pipe.

Note: Position A is preferred. Positions B and C are difficult and require caution. Positions D and E should be avoided.

10. Geotechnical Investigation and Reports

10.1. Detailed geotechnical investigations should be used to obtain factual information about the distribution and engineering characteristics of soil, rock and groundwater at a site, to the extent required to produce a sound, safe and economical design and allow reliable construction planning for the work. The approach and method may include the following:

- Review of existing information
- Aerial photography
- Historical maps
- Test pits
- Trenches
- Borings
- Large-diameter drilled holes
- Cone penetrometer testing (CPT)
- Geophysical surveys and
- Laboratory testing

10.2. Following important Geotechnical Characteristics should be determined for operation of Microtunneling:

10.2.1. Soil conditions

For cohesionless soils (predominantly sands and gravels), the important characteristics that should be determined include the following

- Grain size distribution
- Coarse fraction, i.e., gravel, cobbles, and boulders, if present
- Unit weight
- Hydraulic conductivity and
- Density

For cohesive soils (clays and silts), the important characteristics that should be determined include the following:

- Moisture content
- Plasticity index
- Unit weight
- Shear strength
- Compressibility
- Consistency (typically in terms of standard penetration test N-values)
- Grain size distribution and hydrometer analysis and
- Coarse fraction, i.e., gravel, cobbles, and boulders, if present

General ground behavior includes the following:

- Firm
- Raveling
- Squeezing
- Running
- Flowing and
- Swelling

10.2.2. Rock conditions- Based on appropriate descriptive criteria, the field subsurface and surface site investigation strategy for projects in which rock is anticipated should focus on determining the following:

- Depth and extent of bedrock
- Rock type (e.g., lithology, classification)
- Rock quality designation (RQD)
- Weathering and alteration index
- Discontinuity set frequency and spacing

- Discontinuity surface characteristics (e.g., aperture, infill material, roughness, shape, joint roughness coefficient)
- Presence of fracture-controlled groundwater
- Discontinuity orientation (e.g., strike and dip direction) and
- Point load strength

After the field investigation phase, laboratory testing should be completed on select samples obtained in the field, in order to arrive at reasonable estimates of the following:

- Hardness
- Unconfined compressive strength
- Intact rock or joint direct shear strength
- Tensile strength
- Punch penetration
- Abrasiveness
- Mineralogical Characteristics
- Boreability and
- For clay shale, slake durability and swelling tendencies

Depending on the depth of burial, the geologic region of the proposed work, and the project risk, additional field testing may be necessary, including determination of in situ rock mass modulus of deformation or horizontal stresses through pressuremeter testing.

10.2.3. Groundwater conditions:

Groundwater conditions have a significant influence on ground behavior, and therefore on the design and construction of the jacking and receiving shafts, the selection of the MTBM, and the operation of the MTBM. The type of contamination, location, degree of contamination, and extent of contaminated ground and groundwater should be determined to assess the effect of the contamination on the final alignment and construction materials, including pipe and joint materials. Contaminated ground and groundwater should be avoided, if possible.

Realignment of the project should be considered in an effort to avoid the contaminated ground and groundwater, and to avoid affecting the associated contaminated plume.

10.2.4. It is not the intent of this section to provide detailed guidance on conducting all site investigations for a specific Microtunneling project. All projects are different and require site-specific investigations. Mixed-face conditions, presence of gravels, cobbles, boulders, gas reserve in alignment, contaminated ground or groundwater, potential buried objects etc. must also be taken care in geotechnical investigations.

10.3. Geotechnical Report

10.3.1. All subsurface data collected in connection with the geotechnical investigation, professional interpretations thereof, and design and construction considerations should be summarized in project reports.

10.3.2. These reports typically present summaries of the geotechnical data, interpretations of the data, information about earth pressures to be used for design, discussions of the expected behavior of the ground, and other geotechnical information as well as design recommendations, such as for appropriate tunneling and shaft types and systems.

11. Cost Considerations

11.1. Cost is an important consideration when comparing Microtunneling with other construction methods. Direct costs should not be the only consideration. Microtunneling has other benefits that should be considered when evaluating construction options. Microtunneling has proven to be an economical choice over traditional open-cut construction when all direct costs are included and when the depth of the installation is approximately 6 m or deeper. Various factors to be considered while assessing project cost for Microtunneling are discussed below:

11.1.1. The direct cost of microtunneling is affected by geotechnical conditions and geology, objects along the alignment, groundwater, location, depth and diameter of shafts, length of microtunneling drives, total footage, spoil and slurry handling and disposal, curved alignments using straight drives, type and diameter of jacking pipes, etc. In general, costs increase as the clay content increases, for excavation in rock, with increased size and complexity of the slurry separation plant, increase in distance of spoil disposal site, contaminated ground or groundwater. Cost of pumping and disposal of nuisance water increase with increasing shaft depth, pipe design and pipe material may also affect the cost of projects. Utilities may require relocation, replacement or incorporation of protective measures, which may affect the cost of project.

11.1.2. Indirect costs of Microtunneling includes factors like vehicle traffic disruption, disruption to business activities, loss of tax revenue, disruption to residences, carbon footprint, noise, dust, odors, restoration costs for pavements, public safety; etc.

11.1.3. Environmental and contingency cost shall also be assessed for the project and then a risk analysis shall be done.

12. Submittals

The contractor should submit the items listed in the specifications as agreed between contractor and Zonal Railway for review and acceptance by the Railway Engineer. The submittals are generally divided into pre-construction and post-construction submittals.

Further Reading & References:

- IndSST: 102-2018; Code of Practice for Microtunneling & Pipe Jacking Technique Suiting Indian Conditions.
- IndSTT: TSG: 101 – 2010; Trenchless Technology Selection Guidelines 2010.
- IndSTT: Manual of Trenchless Project Supervision; By Prof. (Dr.) Niranjan Swarup.
- IndSTT: Trenchless Project Management; By Prof. (Dr.) Niranjan Swarup.
- IndSST: Training Manual for Microtunneling Operation; By Prof. (Dr.) Niranjan Swarup.
- BS-5911-120:1989-Precast Concrete Pipes, Fittings and Ancillary Products
- East Coast Railway Letter No.W-3/Br/24.1/Pt.X/Br.Genl Corres/10148 dated 29.11.2019.
- Method Statement for Tunneling Operation by Central Railway.
- Technical Specifications for Microtunneling and Pipe Jacking by Central Railway.
- Standard Design and Construction Guidelines for Microtunneling (ASCE/CI 36-15)
- Railway Tunnels (November-2018) By IRICEN, Pune
- Technical Instructions on Trenchless Technology by Directorate of Works, Military Engineer Services.

Annexure I

1.0 **Various definitions:**

1.1 **Auger boring machine**: Pipe jacking machine with spoil removal and torque transported to the drilling head by augers.

1.2 **Bentonite**: Solid structure former which consists of clay, which is capable of swelling, for the production of water-based liquid flushing media (e.g. bentonite suspension or bentonite-flushing).

1.3 **Bore-hole**: Mechanically created, approximately cylindrical excavation inside the subsoil.

1.4 **Bore-hole wall**: Area which is formed by the surrounding subsoil.

1.5 **Boring**: The mechanical production of a cavity (bore hole) in the subsoil with appropriate tools. In this case of application the boring can be carried out by soil displacement or removal.

1.6 **Boring head**: Boring tools or a system of tools, which excavate the subsoil at the face of a bore. The term usually applies to mechanical methods of excavation.

1.7 **Boulder**: Mineral with a particle size > 200mm; larger boulder > 630mm.

1.8 **Casing pipe**: Pipe remaining inside the subsoil for taking up and protection of a product pipeline or cable against external stresses.

1.9 **Cobble**: Mineral with particle size > 63mm to <= 200mm.

1.10 **Excavation Chamber**: Located directly behind the boring head of the Microtunneling machine, to collect the spoil excavated at the working face.

1.11 **Flushing fluid**: Controlled circulating fluid inside the bore or the conveying circuit, i.e. liquid, gas or a mixture of both, particularly for removing the spoil from the bore hole, respectively from the working face to above ground and in dependence on the jacking method for the completion of further tasks (also called flushing medium).

1.12 **Filter cake:** A thin layer of clay or polymer from the slurry at the face and perimeter of the formation being excavated. The filter cake is formed through filtrate loss.

1.13 **Heaves**: Vertical soil deformations towards the ground surface.

1.14 **Intermediate jacking station (IJS):** A fabricated steel cylinder fitted with hydraulic jacks, which is incorporated into a pipeline between two specially fabricated pipe segments. Its function is to provide additional thrust in order to overcome skin friction and distribute the jacking forces over the pipe string on long drives.

1.15 **Jacking**: Process moving product or jacking pipes into the bore-hole by pressing, pushing or ramming.

1.16 **Jacking force**: Force caused by the technique applied to overcome the penetration and frictional resistance when pushing-in or ramming-in jacking pipes.

1.17 **Jacking length**: Distance covered between starting and target shaft, usually corresponds to the section length in trenchless installation of drains and sewers.

1.18 **Jacking pipe**: Pipe designed to be installed using pipe jacking techniques.

1.19 **Jacking station**: Hydraulic thrust drive, which is installed inside the starting shaft, for producing the required jacking force, consisting of jacking frame, jacking cylinder, thrust ring and thrust wall.

1.20 **Joint**: Non-restrained, tensile-restrained or restrained joint of the ends of two jacking pipes including the seal(s) (also called the pipe joint).

1.21 **Lubricant or support medium**: Liquid with or without solids which pressed into the annular gap in order to reduce the skin friction between the pipe string and the subsoil as well as in order to support the bore hole wall.

1.22 **Microtunneling**: Unmanned, remote controlled, single-phase, or two phase tunneling method, in which jacking pipes are jacked directly behind a Microtunneling machine from a starting shaft by pressing-in or pushing-in into the subsoil to a target shaft.

1.23 **Microtunneling Machine**: Mobile construction for unmanned jacking of jacking pipes consisting of boring and steering head as well as trailing shield segment(s).

1.24 **Nominal size**: Whole-numbered numeric term for the diameter of a pipeline section, which approximately corresponds to the actual diameter in mm (also called nominal pipe size or nominal jacking pipe size). It either refers to the inner diameter (DN/ID), often only referred to as (DN) or to the outer diameter (OD)

1.25 **Pipe length**: Jacking pipe length plus, if existent, thickness of the pressure transfer ring in uncompressed condition.

1.26 **Pulling-in**: Retraction of the pipe(s) with the aid of pulling forces either simultaneously with the creation or expansion of the bore hole or subsequently into the uncased bore hole.

1.27 **Ramming-in**: Jacking of the pipe with the aid of dynamic impact energy simultaneously with the creation of the bore hole.

1.28 **Separation**: Isolation, respectively separation of the several components of a mixture or other.

1.29 **Separation plant**: Installation for the mechanical separation of the components solid (spoil) and liquid (liquid flushing medium) in order to provide the flushing medium again for the conveying circuit and to make the gained spoil disposable. The separation of solid particles from the flushing medium is carried out by sedimentation techniques or multistage separation techniques corresponding to the in-situ particle fractions of the soil.

1.30 **Shield skin**: Outer, cylindrical steel jacket of the Microtunneling machine.

1.31 **Spoil**: Soil or rock excavated by Microtunneling or Auger boring machine when using boring techniques.

1.32 **Steering head**: Front part of a Microtunneling or Auger boring machine with capability to steer or correct the drilling direction.

1.33 **Subsidence**: Vertical displacement of a whole soil stratum as a result of the removal of soil at a greater depth (in the literature often called settlement).

1.34 **Two phase jacking**: Jacking of pipeline(s) via two working steps (also called two-stage jacking)

Phase 1: Jacking of a pipe string of temporary pipes, respectively a pilot drill string.

Phase 2: Jacking of pipeline(s) with simultaneous pulling-out or pushing-out of the temporary pipe, respectively the pilot drill string into the target shaft.

1.35 **Working face**: Excavation area of a respectively a bore hole in the direction of jacking.