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Boulder detection technologies and its treatments in soft ground tunneling

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1. Introduction

As the number of urban tunneling projects are increased within a soft ground, more and more of difficulties lies to overcome the boulder treatments during the tunnel excavation. This paper covers the major considerations to detect the boulders and existing treatment methods that influence the design and construction of soft ground tunnels which could be excavated by mechanized tunneling machine like EPB shielded TBM or Slurry shielded TBM. The objective of this paper is to establish an knowledge of boulders and study the boulder detection technologies and its optimal treatment methods to suggest the developing requirements of the strong shielded TBM to excavate the tunnels in the complex geological conditions.

Boulders are justified as big dimensional rocks compared with the cobbles, and the gravels, but its real scales are much smaller than the bed rocks which are developed at the construction sites. Therefore, it is not easy to find them along the given alignment of roadway, and railroads during the design and construction stages through the direct boulder detection. However, if the designers find some information related to the possible existence of boulders in a certain geological layers, then, they could better to perform the geophysical exploration and doing the face mapping focusing on the boulder detection during the tunneling works.

1.1 Origins of Boulders

In general, Boulders are defined as solid objects larger than 300 mm (one foot), which is defined significantly stronger than the surrounding ground. Boulders are typically a part of rock blocks of various origins and sometimes carried to the site by stream works, or natural falls from the mountain sides, or frequently transported by glaciers, and often they including the man-made solid materials, too.

Boulders are commonly found in river beds, glacial tills, an at the bottom of slopes. Another source of Boulders is the bedrock itself as a core stones. For example, Doublin Boulder clay is a glacial till which overlies the bedrocks

Boulder size (diameter) and its UCS
1) 0.2 m – 1.6m
2) 2m>
3) 3m>
4) variables

USC: 50-200Mpa

Figure 1. Boulders detected from the ground.

Major Boulders: Granite, Gneiss, Basalt, Gabbros, Quartzite, and so on.

In practice, the hard boulder would neither break up nor pass through spoil holes on either side of the discs, which forced loose boulders to slip sideways off the edge of the head where they encouraged overbreak and made the machine difficult to maneuver. Removing calibration bars from across the spoil holes eased the problem. In addition, plans are being considered to grout from the surface and further boulder filled areas along the route to hold the boulders firm so that improved cutters can break them down.

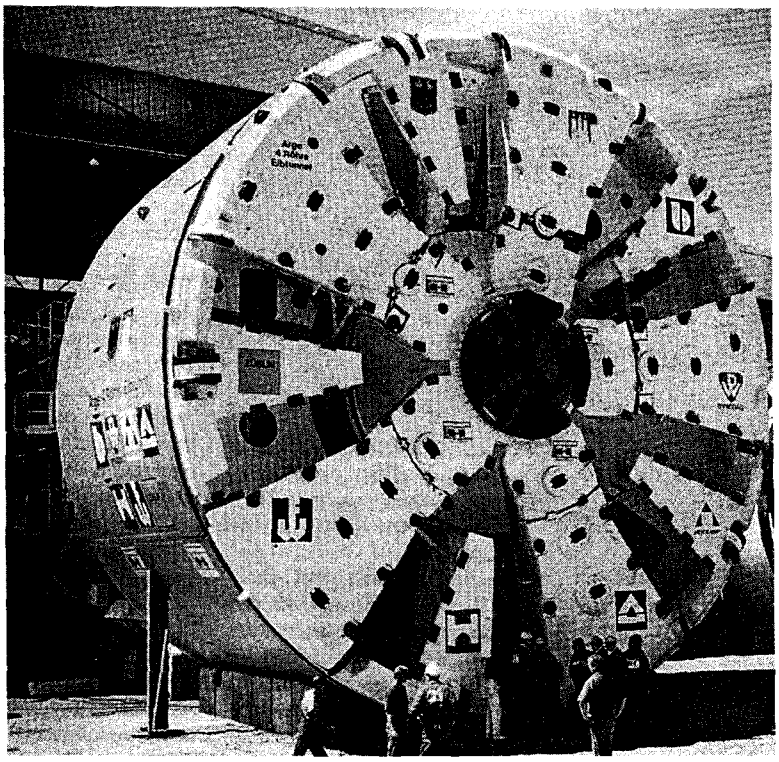

Figure 2. Full Face Shielded TBM.

2. Geotechnical Investigations of Boulder Detections

Normally, the aim of geological and geotechnical investigations is to characterize the natural environment in which an underground structure is intended to be built. The results of such studies form the basis for decisions concerning the general construction method, the specific design of the underground structure as well as for numerical analysis. By means of borehole drilling, the excavation of test pits, geophysical probing and other field methods to geological situation in the project area is classified.

All characteristics which will be encountered during tunnel construction have to be identified, including their spatial relation and the extent of geological boundaries. Furthermore, field or laboratory tests have to be applied to determine the geotechnical properties of the rock or soils.

For tunneling projects the following parameters are needed. (Table.1)

Where the soft ground tunnels in urban area will be excavated with a shielded TBM , then, the mineral content and the abrasively of the penetrated soil and rock layers are very important.

General site geotechnical investigation

- Core drilling (Sampling)
- Geophysics
- General geological pictures
- Geophone (Sonar or seismic systems)

Table 1. Required Geotechnical Parameters for the Tunneling Projects.

Materials	Geotechnical Parameters
Rock & Soil	Specific Weight
	Poisson Number
	Permeability
	Stiffness Parameters (Deformation Modulus, Elasticity)
	Strength Parameters (Friction Angle, Cohesion)
Rocks	Mineral Content
	Abrasivity
	Hardness
Soils	Grain Size Distribution
	Water Content
	Plasticity
	Density
Ground water	Chemistry
	Flow Direction & Velocity

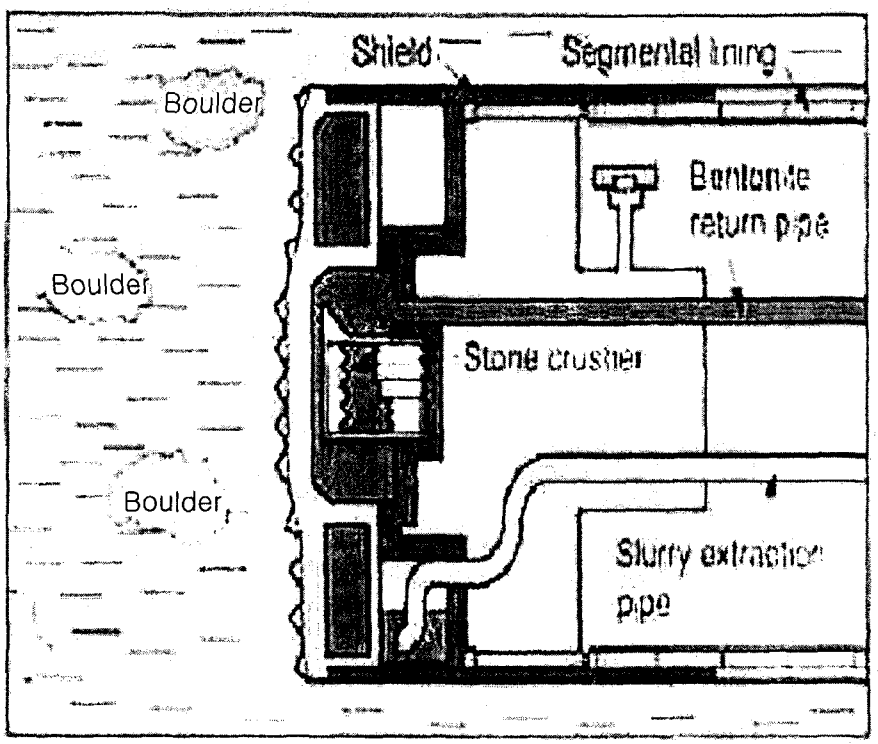

Figure 3. Problems of Boulders at the tunnel face.

2.1 Problems of Existing Geotechnical Investigations

Due to the small drilling diameter (NX: 76mm) and the flushing method it is impossible to define the exact composition of boulder, gravel, and cobble layers. The problematic in particular with respect to the choice and operation of the shielded TBM. Also the other question, whether the jet grouting technique is applicable largely depends on the exact composition of sand/gravel/cobble/boulder layers for the effective pre-reinforcement to increase the face stability. Every soft ground tunnel projects have a crucial questions which is whether boulders have to be expected during tunnel excavation or not. When the boulders spread in sedimentary layers, however, are difficult detect by drilling.

Due to its implications on shielded TBM design and operation the position is of special interest. Seismic tomography and seismic sounding from the surface are definitely good methods to trace the bedrock boundary, in particular since there seems to be a distinct physical contrast between the sound bedrock and its cover.

2.2 Boulder detection at the design stages

For soft ground tunnels, key investigations are focused on the Boulder distributions and the groundwater conditions along the designed alignment.

If the boulders are presented in the soft soils, and rocks,

1) Boulders can be the resistive target around the electrically conductive conditions.
2) Elastically, boulders can be the locally high velocity anomaly in the low velocity zones.
3) Response to the radar waves, boulders have a different electromagnetic property like as electric conductivity, magnetic susceptibility, dielectric constant, etc., with the surrounding materials, and boulders have a unique reflection to the radar waves.

It is supposed to be able to use the electrical resistant exploration, the seismic exploration, and the ground penetration radar-(GPR) methods to detect the boulders. Some of the possible methods are suggested the electric resistivity tomography (ERT), surface seismic reflection survey, and GPR methods in practice.

But, the depth of exploration target is deeper, the ERT and seismic survey have a difficult by the shortage of analysis limits, and the GPR has a low detect ability by way of reduction of penetration energy.

Therefore, ERT and Seismic surveys are available in the target depth range between 20 and 30m. However, GPR method has an accuracy from 5 to 10m range of the target depth.

Normally, ERT and Seismic refraction methods along the alignment are carried out to detect the boulders in the massive hard rocks, after they get the results of analysis to classify the geological layers like soils/ soft rocks, then they can do the more accurate survey at the suspicious area by the 3-D exploration, geotomography, or core drill works. Geotomography can be achieved by the seismic wave, electrical resistance, and Geo-radar.

Figure 4. Geologger-3 is a Multi-purpose Field Data Logger.

2.3 Boulder detection at the construction stages

1) Seismic reflection methods in tunnels

Seismic reflection method in tunnel TRT method by NSA in Colorado, HSP, and TSP method by Amberg in Switzerland are famous commercial code for this survey ways in underground space during tunneling to take the

source by the small blasting or noise generated by rock breaker through the tunnel excavation. Through the source which is generated by the tunnel excavation, and collect the reflect signals from the front face discontinuities like faults, fracture zones, cavity, and boulders, to detect the position of those through the analysis of the reflected data. However, the accuracy of this method is measured very low, because of the data receiving system in the underground conditions, because of the shortage coverage of the cross-hole tomography.

Especially, boulders have a very small scaled anomaly compared with its wave length, which acts the very small reflection signals, therefore, this method only have a possibility to find the boulders in the 5m distance from the working faces.

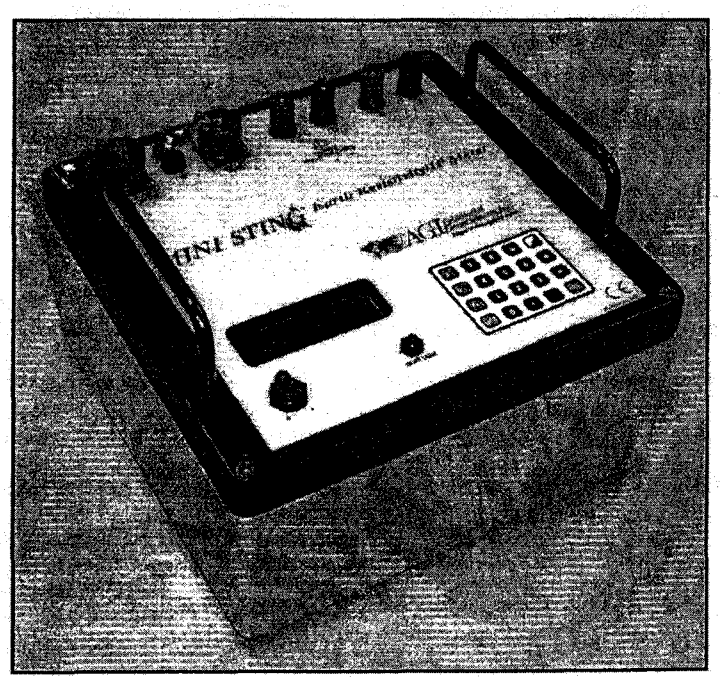

Figure 5. New Geophysical Electrical Resistivity Instrument.

2) GPR survey

In general, GPR survey has a limited survey range in soil layers less 5m distance, but this method is very simple and cheap method, they can use it every tunneling working face to guess the frontal geological conditions at the working face. However, it can not cover the above area of the working face, only possible to discover the just parallel front area from the working site, sometimes, with this survey system mistake to search the boulders above the working faces cause the fatal dangers.

3) Pilot core drilling method

This is the reasonable method to check the existence of boulders by the parallel core drill works in the expected boulder reserved area.

4) Special Geophysical Probe System

The variation of soil materials will be much easier to predict with a forward looking geophysical technique. A possible method is seismic prospection in soft ground which is currently used in EPB and Slurry shield machines. The description of a system, which has been used with success, is presented below:

The Sonic soft ground probing system continuously monitors the soil formation ahead of the tunnel face. It is permanently installed in the cutter wheel of the shield machine. This device serves to perform the following.

- To classify soft ground in terms of strength, homogeneity and other physical characteristics.
- To localize and define planar discontinuities ahead of the cutting wheel. Planar discontinuities can be distinct changes between geological formations, for instance from soil to rock, or fault zones.
- To detect and localize irregular bodies and obstacles within a range of about 50 m ahead of the tunnel face.

This sonic system provides the results immediately after the measurement, such that appropriate tunnel construction measures can be adopted before zones of potential problems are excavated.

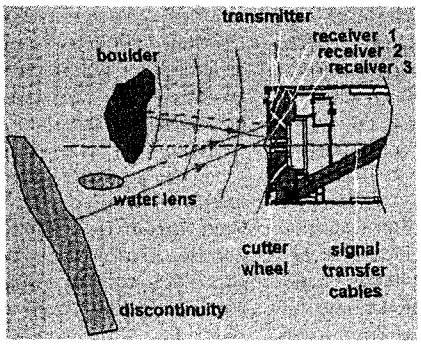

Figure 5. Boulder Detection by Sonic System.

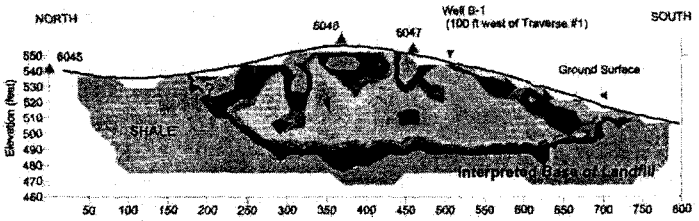

Figure 6. The Results of Geophysical Resistivity and its Images.

3. Handling of Cobbles, Boulders and Core Stones

The presence of cobbles and, to a lesser extent, of boulders and core-stones is a significant feature of the formations to be excavated. Clarification is required as regard to the equipment for handling cobble, boulders, and core stones. The Shield machine shall be provided with a robust cutter head with double bladed cutter disks, which can break boulders and remove the debris.

There is no need for a special method to handle cobbles with a size of under 120 mm. The cutter head and the mucking system are designed to operate in the presence of this type of material.

As far as bigger boulders and core-stones are concerned the cutter head will break most of them by means of the twin disk cutters, though the handling of these boulders will lead to a reduction in the penetration rate. A certain big Slurry type shield machine shall be equipped with a stone crusher, which can crush boulders up to a size of 500 mm diameter.

Occasionally, some of the boulders are not crushed by the cutter head because the soil matrix allows the boulder to move. In this case the boulder, driven by the cutter head will start to spin in front of the machine, impeding the excavation process of the TBM. For the better resolution, the machine must be stopped and prepared for intervention inside the excavation chamber.

For access to the excavation chamber it will first be emptied, keeping the require pressure by means of compressed air in order to support the tunnel face and to prevent water inflow. The working crew can enter the chamber through the airlock, to work from behind the cutter head. The boulder will be broken up with hydraulic breakers, or drilling with hand held drilling machines and then be crushed by blasting or expanding mortar.

After the boulder is crushed the shield machine resume normal boring operation.

4. Conclusion

Practically, the GPR method is not possible to ~~be~~ equipped with TBM, and pilot boring system requires to install the special equipment to work on the TBM at the site.

Seismic reflection method inside the tunnel will not disturb the TBM operation, but it will take long times to the installation of the measuring system at the site, and also requires to ask the expensive analysis cost with the involvement of specialist.

With the present status of arts, there are no confidential survey methods for the boulder detection with reasonable cost, and it is hard to guess that the reasonable boulder detection could not be able to be developed in a near future.

The modified pilot boring system like LIM system will be more attractive to develop the boulder detection systems during the tunnel excavation for the tunnel contractor to increase the better operation rate of TBM machines.

5. Recommendations

When boulders are spreaded at the tunnel face, tunnel advance should be halt, and creating very expensive delays, and result in the construction claims.

Cutters need to break the boulders too large to fit into the machine mucking system

It is necessary that we try to find the general boulder cutters extremely effective to treat boulder cut.

Disc cutters can attack an destroy very hard boulders of any shape, as long as the stone is held firmly in place by the imbedding soil matrix (Anheuser, 1995)

Current method of boulder behavior prediction: by bearing capacity (Terzaghi) equation based on the point load, and shear strength around the boulder during excavation.

Therefore, following recommendations will improve the soft ground tunneling technologies in a near future.

Geotechnical Approach

1. Cutting test to select the optimal bit design
2. Scale model test: movement of boulders, and ground movements during excavations (Test rigs, sensors, recording system, and so on)
3. Numerical analysis: Ground settlements and behaviors around the tunnel
4. Scale model tests, numerical analysis: Boulder treatments, new designed machine cutting activity in the boulder zone
5. Boulder detection device development by geophysical approach
6. Direct drilling method with more than 12 inches diameter on the sensitive area to collect the cobble, and boulder samples with seismic sounding survey

Manufacturer's Attraction

1. High technical improvements of their shielded TBM to get the higher completion rate around the world soft ground TBM markets.
2. To overcome the boulder treatments problems

Designer's choice: Optimal machine selection criteria

Contractor's advantage: To reduce the delay scheduled risks during the tunnel excavation to keep the given contract periods.

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