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A Review On Grouting Techniques For Various Geological Conditions Encountered In TBM Tunnel.

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ABSTRACT:

This paper is regarding study on grouting techniques for various geological conditions encountered in TBM tunnel. Grouting is ground improvement technique in geotechnical engineering. It has been observed that various different types of rock masses are encountered while excavation in tunnels and this affects the overall progress of tunnel advancement, if the encountered conditions are not pre-envisaged. If the tunnelling is continued without considering the adverse conditions, then the possibility of tunnel failure is a possibility. As a solution, sodium silicate grouting technique need to be studied and Engineer's need to be prepared and implement grouting techniques considering the possible rock mass which can be probably encountered as studied in Geotechnical baseline report.

Keywords: Grouting, Tunnel Boring Machine, Rheology, Tunnelling, Sodium Silicate.

I. INTRODUCTION

The standard grouting sequence used during tunnel excavation includes primary grouting, secondary grouting and tertiary grouting.

The primary grout is applied through the injection points of TBM segments. Primary grout is applied just after the segments are placed and this grout acts as a protective cushion between the excavated rock mass and the TBM concrete segments.

Secondary grout is injected through the segment grout socket after completion of primary grout to conceal the voids if any.

Tertiary grouting is done in specific locations where there is a water ingress even after injecting primary and tertiary grout.

There are various methods to control the stabilization of soil and rock mass to launch or breakthrough the TBM successfully. This is done for to control soil stabilization to work out the cutter head intervention.

II. TYPES OF GROUTS

1. Cement Grout

Cement grout consists of cement, water and admixture in ratio as per the approved mix design. The water cement ratio usually applied is 0.45 and this varies from site to site as per the ground conditions and lab trials.

Cement grout is applied in fore polling of rock face from where the TBM is launched and retrieved. This acts as a slope stabilization measure and avoids lateral failure while launching and retrieving of TBM.

Cement grout is also applied as a secondary grout at specified intervals and most importantly at the locations where there is presence of dampness/ water ingress in TBM tunnel. While injecting cement grout as a secondary grout it is ensured that the grout is flowable, as the same needs to easily flow through minor cracks in the primary grout.

2. Sodium silicate

Sodium silicate grout consists of cement, water, admixture and sodium silicate. This grout is used as a primary grout for filling the void in between the excavated face and the extrados of TBM tunnel rings.

The water cement ratio generally lies is in between 1.5 to 2.2 and this varies from site to site as per the ground conditions. Addition of sodium silicate accelerates the setting time and even the early strength is achieved within 24hrs of application.

3. Polyurethane injection Grout

Polyurethane injection grout also named as PU grout is applied at the locations in TBM tunnel where there is presence of dampness/ water seepage even after injection of primary and secondary grout. PU grout mix consists only of polyurethane which is injected through the injection points and upon contact with water this grout swells and forms a foam like barrier.

III. LITERATURE REVIEW

There has been growing research in tunnel grouting over last few decades. Ali H. Shareef and Mohammed A. Al- Neami (2023) discussed about the effective method for soil stabilization with various chemicals like cement fly, ash, slag and admixtures. This research mainly focuses on suitable method to reduce water content from soil with use of relevant admixture like silicate, lignosulphates, phenoplasts, amoniplast, aerylamides, polycrylamicles, acrylate etc. From the above, it was concluded that, the proper method of soil stabilization is mixing of admixture grout deep into soil (DMM) with pipe of dia 0.5-1.0 m and depth around 25.0m. This method is applicable for treating soft soil.

Christian Butrón and Gunnar Gustafson (2012) discussed about the method to reduce the water ingress in tunnel after ring building by application of grout with accelerator like silicate. The focus of this this paper is to minimise the dripping location in tunnel by reducing water ingress. It is researched that the design of grout needs to be done so as to fill up the gaps of fracture zone. In view of this, the viscocity of this mix needs to be good for filling maximum voids of the cavity.

Cong Zhang and Junsheng Yang (2019) discussed that Grouting in loose soil tunnel often shows its negative points like variation in gel time, weak stability and extra consumption of grout. The properties of grout were studied and a grout mix was prepared on the basis of three-dimensional network structure with grouting ingredients like sodium silicate, polyethylene glycol (PEG)200, cement and PS. It was observed that, this mix is good for pumping and gives better early compressive strength and minimum permeability. Further, this mix of grout is excellent in grouting performance and mechanical characteristics.

Brendan M. Harkins and Dominic M. Parmantier (2012) discussed about the live site execution example wherein unexpected boulders were encountered at Portland, Oregon during launching of lovat tunnel boring machine. During mining boulders were stuck in cutter head. These boulders were cleaned by drilling it by hand drilling machine. It was observed that the PU grout used for stabilizing the excavated face also failed. So to tackle this loose soil situation cement and sodium silicate grouting was used for stabilizing the ground by SPP sleeve pipe system. For this grouting small access is required to install sleeve pipe (SPP) and straddle packers up to depth of 20.7m. (up to the crown of TBM). This method is adopted for chemical grouting into the granular ground condition and at necessary points tertiary grouting was also done as per water testing. The Grout mix contained water 45%, sodium silicate40%, reactant 15% by volume. So SPP grout injection system provided control of the grout placement, ensuring fall grout coverage through the target zone.

V. Ganeshan and OW Chun Nam (2008) discussed about open end tube and tube -A- machete (TAM)

grouting along with illustrations. This paper focuses of, In land transport authority (ITA) circle line 4 (CCL4) projects wherein different types of grouting's were used during tunnelling and excavations. Author gained experience in open end tube grouting and packer grouting and the same is described with their recent applications in CCL4 projects. In AYA mines tunnel there was presence of water ingress and loose soil from the crown area wherein crown was prevented from collapsing by single packer grouting through the roof pipes. Ground water flow and ground settlement in tunnel mining completely was stopped by using open end tube grouting.

Sina Kazemian and Arun Prasad (2012) discussed in this paper about the behaviour of cement, sodium silicate and kaolinite on the rheological behaviour of grout. There are various different verities developed in sodium silicate as a accelerator. Rheology gives an detail idea about homogeneous grout. Shear stress and shear rate relationship are described in rheological model. Newton model, bingham model, power-law model, modified power law model and cason model are used for suspension rheology. The authors observed that by increasing the amount of cement, kaolinite and sodium silicate (with high ratio) the viscosity of grout increased. On other hand by increasing the water ratio, viscosity is decreased. The shrinkage increased with an increase in sodium silicate and decreased with an increased in cement content. This happens since the hydration and pozzolanic reactions of cement, ion exchange between calcium ions and the ions present in the mineral part of grout form colloids, which polymerizes to form a gel that binds soil particles together.

Eduard Falk and George Burke (2003) discussed that the current development in urban tunnelling excavation methods are a threat to existing structures. In view of this, design concept are important for grouting in urban tunnelling. This paper focuses on settlement prediction, potential damage assessment, settlement reduction, damage reduction and remedial grouting after a tunnel collapse. It was concluded that, to reduce the settlement ratio before and after excavation or mining of tunnel dedicated grouting methods need to be used.

Xiao-chun Zhong and Quan-wei Liu (2011) discussed that one of the most important control parameter in grouting is grout pressure for tail voids grouting, it has a command on volume of grout, and it's one more control parameter for backfill grouting. During the erection of lining segments in shield tunnelling, a gap is found between shield of TBM and and extrados of segment. It is mandatory to inject grout into the gap to actively control ground deformation. This paper focuses on relationship between grouting pressure and filling rate of shield tail void, grouting pressure and grout characteristics. And determination of grouting pressure.

IV. OBJECTIVE OF RESEARCH

The objective of this paper is to tackle the ground condition with sodium silicate grout mix by taking in consideration the geotechnical baseline report. Wash out of grout due to ground condition and presence of water needs to be tackled appropriately.

V. RESEARCH

From above mentioned literature review it has been observed that the type of grout and its composition varies from ground conditions. Wherein as per usual practice on site, a standard mix design of grout is prepared and applied unanimously for the entire stretch of tunnelling, but this leads to issues such as grout wash out, cracks in grout, etc.

In view of this it is studied that the grout mix needs to be applied as per the ground conditions. This ground conditions are pre envisaged in the geotechnical baseline report.

I. Sodium silicate grouting in ideal ground strata – The ideal ground strata is considered wherein there are minimum joints and no water ingress. In such ideal ground the following sodium silicate two component grout mix can be applied.

Table 1: Grout mix-design for ideal condition.

Material	Weight in Kg/ m3
Cement	420
Water	763
Bentonite	20
Stabilizer	2
Sodium Silicate	130

This grout mix gives a viscosity of 36 with a gel time of 12 seconds. The ideal application pressure for this grout is 2.5 bars. This grout with above mentioned viscosity and average 24hrs strength of 2.3 Mpa is effective in ideal ground condition where there is no water ingress.

II. Sodium silicate grouting in moderate ground strata - The moderate ground strata is considered wherein there are moderate joints with moderate amount of water ingress. In such ideal ground the following sodium silicate two component grout mix can be applied.

Table 2: Grout mix-design for moderate ground condition.

Material	Weight in Kg/ m3
Cement	380
Water	760
Bentonite	20
Stabilizer	2
Sodium Silicate	150

This grout mix gives a viscosity of 30 with a gel time of 10 seconds. The ideal application pressure for this grout is 2.5 bars. This grout with above mentioned viscosity and average 24hrs strength of 2.5 Mpa is effective in moderate ground condition where there is moderate water ingress. This reduction in viscosity allows the grout to easily flow through the voids between the strata. The 24 hrs strength of 2.5Mpa is effective in tackling the moderate amount of water ingress/moisture within the ground condition.

III. Sodium silicate grouting in fracture ground strata - The ideal ground strata is considered wherein there are the ground strata is highly fractured with significant amount of water ingress. In such ground the following sodium silicate two component grout mix can be applied.

Table 3: Grout mix-design for fracture condition.

Material	Weight in Kg/ m3
Cement	350
Water	750
Bentonite	20
Stabilizer	2
Sodium Silicate	190

This grout mix gives a viscosity of 28 with a gel time of 14 seconds. The ideal application pressure for this grout is 3.0 bars. This grout with above mentioned viscosity and average 24hrs strength of 2.5 Mpa is effective in fracture ground condition where there is significant water ingress. This additional reduction in viscosity allows the grout to easily flow through the voids between the strata and also reduces the micro voids within the grout. The 24 hrs strength of 2.5Mpa is effective in tackling the significant amount of water ingress within the ground condition.

VI. CONCLUSION

The sodium silicate grout mix is effective in different ground strata only when the mix is designed considering the details of available ground condition as per Geotechnical baseline reports.

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