Pregrouting of Rocks During Construction of Underground Railway Tunnels

By Yu.N. Spichak[1] and A.N. Grinenko[2]

[1] STG, 349240, 7a Petrovski Street, Antratsit, Lugansk Region - Ukraine
[2] Novocherkassk State Technical University, 346500, 6 Lenin Square, Shakhty, Rostov Region - Russia

ABSTRACT

The paper gives a description of a pregrouting technique applied during construction of underground railway system at depths from 10 to 50 m. Pilot holes drilled either from the ground surface along the route of the tunnels or from their work faces were employed in order to ensure safe excavation activities. Fractured and weathered rock strata were treated with clay-cement grounts, for unconsolidated ground cement-sodium silicate mixtures were used. The paper is concluded with case histories which describe pregrouting procedures during tunnelling for the Dnepropetrovsk City underground railway system in the Ukraine.

INTRODUCTION

The earlier practiced grouting technique developed by STG consisted of preliminary sealing of the water-bearing strata which will be intersected by the underground headings. The length of grout injection holes was in the range of 100 - 150 m.

Applying this approach a grout curtain with the designed configuration and size is being emplaced through 1 - 2 horizontal or angle boreholes by injecting visco-plastic grout mixtures into the saturated fracture zones or separate features. Injection pressure is calculated with regard to the groundwater hydrostatic pressure, fracture aperture, rheologic, and structural-mechanical properties of the grout material, and excavation depth.

Preparation and injection of grout is executed by utilizing mobile cementation equipment located on the ground surface and through high-pressure ranges running from a grouting pump, down a shaft, and along the heading to the working face. Grout is injected into water-producing zones through a DAU - 1 packer with outer diameter of 73 mm to ensure the placement of the designed grout quantity with the designed pumping pressure and rate. The process of grout curtain formation with the required size and counter-filtration properties is being continously monitored. This practically excludes any ingress of ground water into the heading during its excavation in the grouted strata.

GEOLOGICAL FEATURES

When pre-grouting technology applied at great depths is compared with the same method at shallow depths (10 - 50 m), the following features have to be taken into account:

- ground weathering

- possible deformation of the overlying strata and ground surface

- grout can potentially escape to the surface while operating through shallow holes.

STUDIES

The development of water sealing pre-treatment technology for excavating shallow subsurface openings has been by analytical and experimental studies into the process of flow of visco-plastic grout material in the fractured massif encountered at a shallow depth.

These studies resulted in determining the pressure losses ΔP occurring during grout propagation in the neighbourhood of an underground opening which will depend on the aperture and spacial orientation of fracturing and strata properties.

The relationship describing the occurred pressure losses P has been used to derive an equation which describes the size of a water sealing curtain R being created in fractured water bearing strata around shallow underground excavations.

The equations derived allows it to be applied to the design of the injection holes drilled both from the ground surface and from the excavation faces, and to determine the required volumes of grout injection within the specified drivage intervals.

PRINCIPLES OF TECHNOLOGY

STG has developed and broadly applies in underground construction activities a new technology for safe excavation of openings encountered at shallow depths. The essence of this technology consists in grouting fractured water-producing zones by clay-cement grouts and stabilizing incompetent and unconsolidated quartenary sediments by filtrational consolidation during cement-silicate grout injection at specified pressure and at the interface of bedrock and quartenary deposits.

Consolidation of incompetent ground occurs as a result of fracturing and filling the created flow-paths with grout mix. This is accompanied by the pressurization of unstable ground under the impact of external pressure generated by the relevant grouting equipment.

A sharp growth of rheological and structure-mechanical properties of grout which results from the outfiltration of a liquid phase from the grout mix. This is dictated by the specified design pressure and provides for creating a stable and competent skeleton in quarternary ground.

APPLICATION SITE

The developed technology for preliminary water sealing and consolidation of incoherent ground is being broadly applied during construction of an underground railway network in the city of Dnepropetrovsk, Ukraine.

Construction of by-pass tunnels in this underground railway system was designed ata depthof 15 m where the predicted water inflow amounted to 150 m^3/h. The water producing zone consisted of fractured plagiogranites with sand interlayers. Ground freezing through freezing columns set along the route of the tunnel was selected for ground water control during excavation. Still, on the completion of ground freezing when the left by-pass tunnel was excavated there occurred an ingress of water at a rate of 100 m^3/h. As a result of this, tunnelling operations were discontinued. The inrush generated ground subsidence and affected the integrity of thefrozen ground block.

DESIGN PROCEDURES

To ensure safe excavation of the left by-pass tunnel, STG prepared a grouting programme design to treat problematic zone of fractured and incoherent ground in the interval between stations 59 - 80 and 60 - 10. The designed plan was to execute grouting at stages which will be described in the Application section. The designed radius of grout spread from an individual borehole amounted to 5 m, injection pressure for cement-silicate grout was 1 - 1.5 MPa, for clay-cement grout 4 - 6 MPa. The following values derived from the data of hydrodynamic tests were included into calculations:

- minimum fracture aperture -2 x 10-2 m,
- maximum fracture aperture -7 x 10-2 m,
- hydrostatic pressure head - 0.1 MPa,
- fracture porosity - 3 per cent.

As per calculations made, the total designed volume of clay - cement grout injection was 550 m^3, and of cement-silicate mix was 180 m^3.

APPLICATION

The sink hole on the ground surface was first filled with a sand-gravel mixture, and for strengthening the incoherent tunnel's roof strata in the zone of ground subsidence 80 m^3 of cement-silicate grout was injected. Cement-silicate grout was pumped at a no-pressure regime via 42 mm - dia. drill - pipe column which had been lowered to a depth of 9 m.

The 2nd stage in the elumination of remaining voids was performed in the interval of 0 - 9 m. This was accomplished by injecting 90 m^3 of clay-cement grout via 42 mm - dia. drill pipe column which had been owered to a depth of 5 m. The implemented programme of grout treatment resulted in the stoppage of further ground subsidence.

At the 3rd stage 18 vertical boreholes 16 m deep each were drilled with an objective to strengthen incoherent rock strata encountered in the interface of eluvium with plagiogranites, and also for emplacing a cement "umbrella" above the grouted zone aimed at preventing future inrushes of the injected grout to the ground surface. This was achieved by injecting 4 - 6 m^3 of cement-silicate mixture into each borehole. The grout injection boreholes were cased with 112 mm - dia. casings to a depth of 15 m. The spacing between adjacent boreholes amounted to 3 m (Figure 1). At the 4th stage the boreholes were deepened to a depth of 32 m for sealing fractured plagiogranites. The final boring diameter was 93 mm.

A programme of downhole hydrodynamic investigations was conducted in each borehole in order to define the actual fracture parameters and hydraulic properties of the problematic strata. As a result, 3 major water bearing zones were detected into which through the first 6 boreholes there was executed the injection of the main portion of clay-cement grout, i.e. from 25 m^3 into each hole. The remaining boreholes were treated with from 2 m^3 up to 12 m^3 of grout. The average parameters of grouting in the first 10 boreholes are presented in Table 1.

Type of grout ad mixture	Borehole depth m	Grout Injection										Injection pressure MPa	Backward pressure MPa
		1	2	3	4	5	6	7	8	9	10		
cement-silicate	16	6	6	5	4	6	5	5	4	6	6	1 - 1.5	0 - 0.5
clay-cement	32	135	60	66	25	32	27	10	12	8	12	4 - 8	2 - 4

Table 1

The overall actual quantity of grout material injected amounted to 90 m^3 of cement-silicate grout and 440 m^3 of clay-cement grout.

Quality assurance of grout treatment process was executed in the course of grouting based on the designed value of grout injection pressure at a borehole head, reduction of the original permeability of the strata, and by pressure testing the grouted massif.

GROUTING PROGRAMME RESULTS

On the completion of grouting the left by-pass tunnel was sucessfully completed in the interval between stations 59 - 80 and 60 - 10.

Numerous grouted fractures with apertures from 0.001 m to 0.05 m were exposed during tunnelling at the interface with loose sediments and in plagiogranites. No water seepages occurred within the grout - treatment zone. In the course of excavation the tunnel face was exposing propagation zones of cement-silicate and clay-cement grouts.

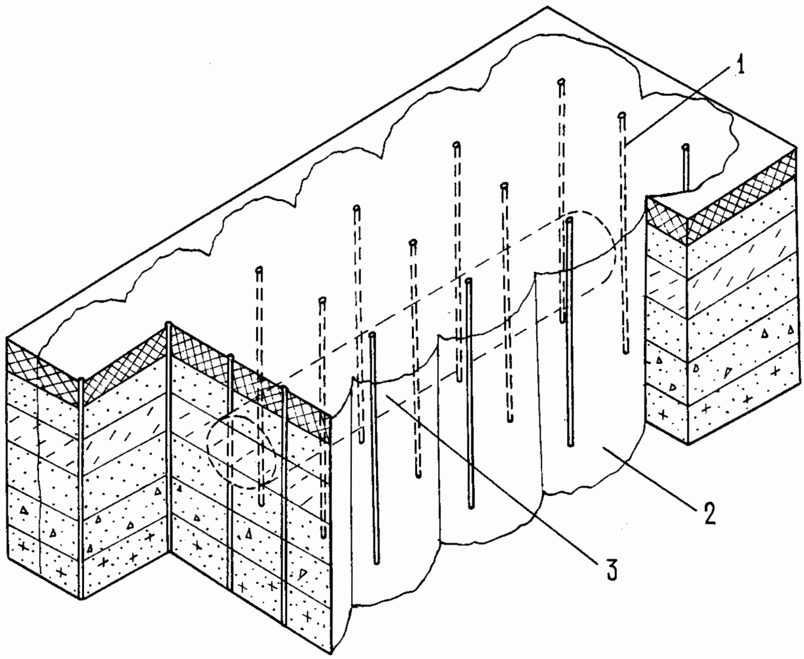

Fig.1 Schematic view for emplacing water sealing curtain around underground railway tunnel between stations 59-80 &60-10

1 - grout injection borehole, 2 - grout cover created from one borehole, 3 - underground railway tunnel

CONCLUSIONS

Based on the above description one may state that the developed technique for strengthening and water sealing of incoherent ground during excavations at shallow depths enables the following:

- to increase excavation rates and its safety,

- construction of underground installations in complex urban-development environments,

- effective and reliable implementation of projects related to pre-grouting and ground stabilization under diverse hydrogeological and geochemical environments utilizing cost-effective and ecologically clean materials.