CONSOLIDATION OF TECTONIC RUPTURES USING CLAY-CEMENT GROUTS DURING TUNNEL DRIVING

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ABSTRACT

The paper deals with the basic principles of consolidation technique for water bearing tectonic ruptures using clay-cement grouts during deep tunneling. The application field of this technique is specified with regard to tectonic rupture size, strength factor of ground contained in the ruptures, and depth of tunneling. The actual information on the results of production introduction of this new technique is presented. Consolidation of water bearing tectonic ruptures is conducted by clay-cement grouts which are prepared and injected into underground holes by means of high-production grouting equipment located on the ground surface.

INTRODUCTION

Tectonic rupture piercing during multi-purpose tunneling is a complex problem for engineers. World tunneling experience is indicative of a drastic decrease in the rates of tunnel driving through unstable aquiferous rock encountered in the zones of tectonic ruptures. Side by side with successes attained by some foreign tunneling contractors in driving traffic and hydraulic tunnels, there are some examples when the tunnel direction is changed and its routing is prolonged in piercing through thick, water bearing rupture zones.

All this results in a rise in the cost and time of construction. Depending on geological conditions, the tunnel piercing through ruptures is carried out at present employing the drainage of artesian water, part-face driving technique, chemical grouting, or the use of tunneling machines. The combination of the above mentioned techniques is also often used.

To cut down the time and cost of tunneling under severe geological conditions, there has been developed at STG association and is being introducted in driving the main and auxilliary lines of the Severomuyski Tunnel a technique for tectonic rupture consolidation. This technique is based on the injection of inexpensive and effective clay-cement grouts into prerupture aquiferous zones.

GEOLOGICAL CONDITIONS

The specific features of the site of the 15 km long Severomuyski Tunnel and pilot drainage gallery driven parallelly, are defined by its location in an extremely collapsible seismic zone within the boundaries of a large granitic intrusion intersected by multiple systems of old and young diversely spaced tectonic ruptures. They are characterized by a complex structure, severe water abundance and faulting.

Rupture piercing by the conventional technique results in the washing-out from the excavation roof of sand and clay with a susequent outburst of water-sand mass containing breakage material. Such outbursts are accompanied by the formation of a caving the size of which depends on the size of rupture zone and the strength of ground contained within the rupture. At the moment of outburst the water inflow is maximum, and it ceases after the excavation is filled with water-sand mass. Water is accumulated in the failed rupture zone, and reopening the rupture is much more dangerous.

The mechanism of water-sand mass outburst can be formulated as follows. Redistribution of stresses resulting from the excavation face piercing in loose aquiferous rock is accompanied by deformation in the direction of the excavation. The quantity of deformation results in the failure of rupture core zone near the excavation face, and in the inrush of water-sand mass from the excavation roof. The failure has an avalanche-like character. It results in a new redistribution of stresses, and new failure that ceases only after the excavation is filled with water-sand mass and breakage material. This inrush mass is a kind of a stopping that prevents the increase in a rock mass volume.

Special procedures and strong, expensive lining must be used to eliminate such manifestations of rock pressure.

BASIC PRINCIPLES OF TECHNIQUE

Initial drainage of artesian water in the tectonic rupture zone within the routing of the Severomuyski Tunnel is carried out through a 4.5 dia. pilot gallery driven by a Robbins tunneling machine. The gallery is driven ahead of the tunnel face by 300-350 m. As a result, when the tunnel face approaches the rupture zone, partial strata water level lowering occurs, and the rupture zone piercing is executed by part-face driving.

However, when the tunneling machine intersected faulted zones without the use of special techniques, there were inrushes of breakage material and sand-clay aquiferous mass that resulted in the stoppages of operations. To eliminate these complications, small-cross-section galleries were driven from both sides of the tunneling machine, all this required additional and labour consuming unmechanized work[1].

To enable tectonic rupture piercing by the tunneling machine, there has been developed on the basis of the Integrated Grouting Method a technique for consolidation of ground encountered in the rupture. It is based on the injection of plastic clay-cement grouts into fissured zones before and after the rupture at a pressure of 28-30 MPa. As a result, the ground is compressed that considerably increases its strength, stability and enables the tunneling machine piercing through the compressed ground without complications. In the process of clay-cement grout injection into the zones before and after the rupture, the infiltration of strata water from the rupture core occurs together with the hydrosealing of peripheral rupture zones and ground compression that also improves the rupture stability.

INVESTIGATIONS

In order to define the field of application of this technique, there have been conducted analitical studies on the relationship of pressure changes at the working unit of the tunneling machine in the treated ground with regard to the rupture size and ground strength. To determine the quantity of pressure at the working unit of the tunneling machine, there was a solution principle of a similar task for pipelines in closed deep driving when the rock pressure is calculated with regard to caving.

The conducted analitical studies enabled developing a method for calculating the required degree of rupture ground consolidation when it is squeezed by clay-cement grouts, and methodology for estimating the influence of artificial squeezing on the increase in rupture ground stability.

INDUSTRIAL APPLICATION

While driving the drainage gallery of the Severomuyski Tunnel in the westward direction from the ventilation shaft No.3, a 89-mm long pilot hole encountered three ruptures from 3 to 6 m thick in the range of 31-37 m, 40-43 m and 54-58 m. The ruptures are interlaid with prerupture aquiferous zones, Fig.1. The ruptures include broken loose granites with a strength factor on Protodiakonov scale 0.2-0.3, and the prerupture zones include intensively fissured aquiferous rock with a strength factor on Protodiakonov scale 4+6. During pilot hole drilling there was a considerable water irruption with clay-sand mass. The hole discharge totalled 0.042 m^3/s (150 m^3/hr).

To ensure safe conditions in driving the gallery through the encountered ruptures, there were designed at STG association special procedures on rupture consolidation with high-viscous clay-cement grouts which are injected into the prerupture aquiferous zones.

Consolidation of each rupture was designed to be carried out in succession through 4 horizontal holes from 40 to 60 m long, Fig.1. On the completion of injection into the prerupture aquiferous zones of the designed quantity of clay-cement grout, the project foresaw core drilling of two control holes which could be used as grout holes if needed.

The intersection of the prerupture zone in the first rupture resulted in a water-sand inflow of 0.020 m^3/s (70 m^3/hr) at hydrostatic pressure of 2.1 MPa. To define more accurately the filtration parameters and process patterns, a programme of hydrodynamic investigations was executed[2].

On the completion of testing there was carried out the injection of clay-cement grout. On attaining the designed pressure at a borehole collar the grout injection was stopped, and the prerupture zone was pressurized. After it the hole was redrilled up to the postrupture fissured aquiferous zone in which a grouting programme was carried out in the above mentioned succession.

Further hydrosealing and consolidation of the ruptures encountered in the considered interval were executed according to the project. Major parameters of the performed grouting operations are enlisted in Table 1.

On the completion of grouting there was drilled a 66-m long proving hole. The residual inflow in the treated zone was 0.0013 m^3/s (5 m^3/hr). To cut down this inflow, the proving hole was treated with 66 cu. m of clay-cement grout. While drilling the second proving hole the residual inflow was 0.0002 m^3/s (1.5 m^3/hr).

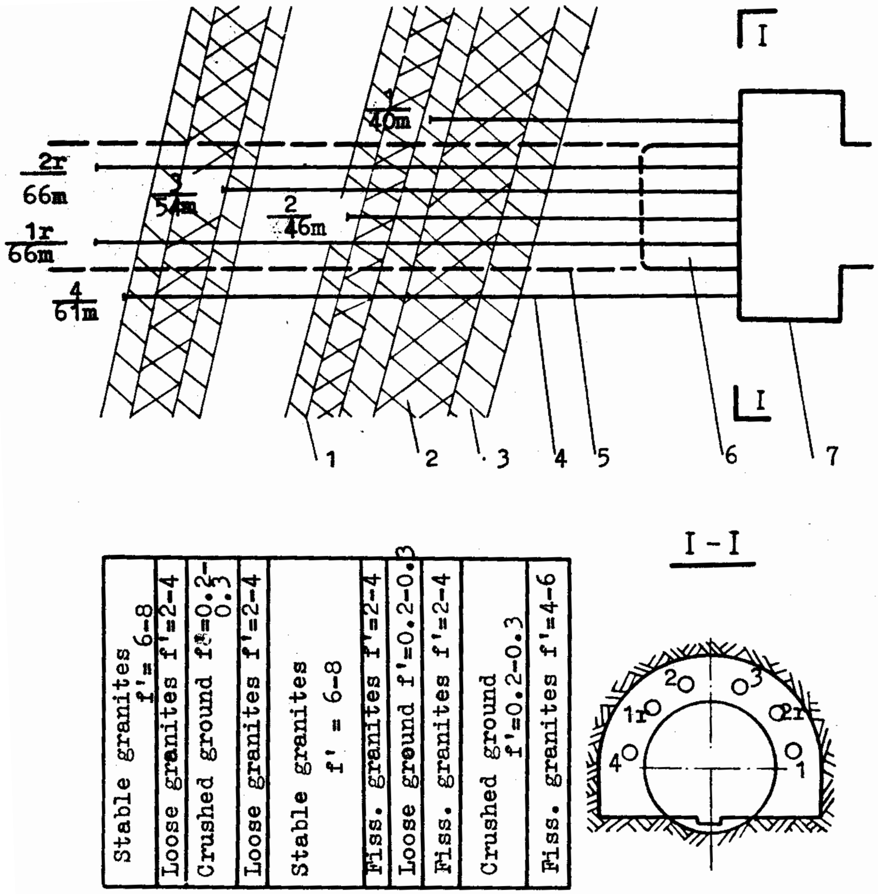

Fig.1. Diagram of tectonic rupture consolidation by clay-cement grouts

1 - postrupture aquiferous fissured zone; 2 - crushed loose ground (rupture core); 3 - prerupture aquiferous fissured zone; 4 - grout hole; 5 - gallery projection; 6 - working unit of the tunneller; 7 - drill chamber

Rupture number	Hole number	Hole depth, m	Water inflow from holes, m^3/s (m^3/hr)	Injection zone, m	Grout volume, m^3	Residual water inflow, m^3/s (m^3/hr)
	1	31	0.020 (70)	28-31	143	0.0008 (3)
1-2		40		27-40	178	
	2	30		27-30	140	
		46	0.015 (55)	43-46	154	0.004 (1.5)
	3	54	0.014 (50)	51-54	366	0.002 (0.7)
3	4	53		50-53	108	
		6	0.011 (40)	57-61	210	0

RESULTS

The residual inflows in the grouted zone were 0.0013-0.0027 m^3/s (5-10 m^3/hr) versus the estimated inflows of 0.9-0.1 m^3/s (330-360 m^3/hr). In the prerupture zones there were detected dozens of variously spaced fissures with an opening of up to 0.2 m filled with compact clay-cement grout. Hydrosealing of peripheral zones and an increase in the strength of ground resulted in a successful piercing through the treated zone with subsequent lining the tunnel.

SUMMARY

The obtained results proved the efficiency of the developed technique for rupture consolidation and we may state the following advantages:

- inexpensive and effective clay-cement grouts are used;
- original methods and devices are used to obtain initial information on the filtration properies of rupture ground and fissuring parameters of prerupture zones;
- it is based on an engineering analysis of rupture ground consolidation during clay-cement grout squeezing;
- efficient technology and high-production equipment are involved;

- a method for estimation the influence of artificial ground squeezing on an increase of the ground stability is used.

Together with the above mentioned the technique provides time saving in rupture piercing, it reduces the cost of tunneling and helps to gain considerable saving because of the pay-back of outlays while cutting down the time of construction and putting the tunnels into operation ahead of schedule.

REFERENCES

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