International Journal of Mine Water, Vol. 3 (3), (1984) 35-41
Printed in Madrid, Spain.

HYDROSEALING AND CONSOLIDATION OF GEOLOGICAL FAULTS DURING TUNNEL DRIVING

B. Ja. Kipko*, Ju. A. Polozov**, and Ju. N. Spichak***
*Professor, Director General, ** Deputy Director General, *** Chief Engineer.
Specialized Association Spetstamponazhgeologia, 7a Petrovski St., Antratsit, Voroshilovgrad Region, USSR.

ABSTRACT

The paper deals with a complex approach to the solution of the present-day problem on hydrosealing and consolidation of geological faults during tunnel driving. New methods for obtaining initial information on hydrodynamic and seepage properties of faults during drilling horizontal holes are presented. These methods ensure efficiency of design decisions on grouting the faults. Techniques of hydrosealing and strengthening of tectonic faults are discussed, and the basic criterions for reliability evaluation are determined.

INTRODUCTION

Tunnelling in unstable water bearing rocks encountered in zones of geological faults presents a complicated technical problem. Depending on the specific features and actual geological conditions during driving through faults employs the use of freezing [1] or strata water level lowering [2], chemical grouting [3] or shielding equipment [4]. Disadvantages of the above mentioned methods are as follows :

- labour and time consumption for the first and second methods
- inhomogeneity and a small radius of strengthening for the third method
- possibility of unpredicted rock mass ingress during rupture piercing by the tunnel shield for the fourth method.

It is also possible to tunnel in weak unstable ground under the protection of a pilot tube screen [5]. However, this method is characterized by high labour consumption because of the necessity to push forward a great number of tubes within the contour of an excavation. At depths more than 100 metres it is not practical in view of the possibility of screen collapse under the influence of rock pressure in the course of rupture piercing.

To reduce time and ensure safe conditions of tunnelling under severe geological conditions, the Spetstamponazhgeologia Association have developed a new reliable method of tectonic rupture piercing during tunnelling through geological faults at great depths based on grout injection into the adjacent zones. At present the new method is being applied in the construction of the Severo-Muiski Tunnel.

GEOLOGICAL CONDITIONS

According to the study by the Institute of the Earth's Crust of the Siberian Department of the USSR Academy of Sciences there is nothing to compare with the severity of the geological conditions encountered in the 15 km long Severo-Muiski Tunnel and pilot pallery driven parallel to the tunnel [6]. The tunnel and pilot gallery intersect numerous zones of tectonic dislocations including large faults with water inflows up to 700 m^3/hr. Moreover, the hypogene faults contribute to thermal water ingress into the workings that is connected with seismic activity of the region. The water inflows include a great amount of sand, gravel and debris that considerably complicates driving.

CHOICE OF INVESTIGATION TECHNIQUE

As a result of a critical review of the conventional methods, generalizing domestic and foreign experience in the field of faults piercing it was possible to establish perspective trends in the development of a new method of hydrosealing and strengthening of faults in tunnelling on the basis of the Intergrated Grouting Method innovated at the Spetstamponazhgeologia Association. The new method must embrace :

- A technique for obtaining accurate information on hydrodynamic and filtration properties of faults which would be the basis for calculating the entire process of hydrosealing and strengthening of fault zones around a tunnel;
- The application of cheap and efficient grouts;
- Optimistic schemes of grout injection from the surface and through underground boreholes;
- Quality control technique for grouting operations.

INVESTIGATIONS

A detailed study and analysis of the severity of tectonic structures filled with unstable loose boulders resulted in establishing the fact that major water flows were associated with intensively fractured zones.

To determine regularities of grout barrier formation in the rupture around the tunnel, an analysis programme was undertaken into the flow of viscous-plastic grouts in fissures. Both impermeable and permeable walls formed by unstable rocks were studied with regard to rheological and structural-mechanical properties of grouts both in time and length of the flow.

The results obtained showed it was necessary to determine sealing barrier parameters, consolidation zone dimensions of unstable rocks and injection pattern regimes for the viscous-plastic grout. These were used as the basis for developing design methods in the field of grouting tectonic ruptures during tunnelling. All calculations are based on the precise information about rupture filtration properties obtained from direct investigations in the grout holes using the DAU-3M-Gr flowmeter.

BASIC PRINCIPLES OF NEW METHOD

The method of driving through geological faults foresees sealing the water bearing fractured zones adjacent to the fault and strengthening the weak fault gauge by simultaneous grout injection into accompanying fault planes (Fig.1).

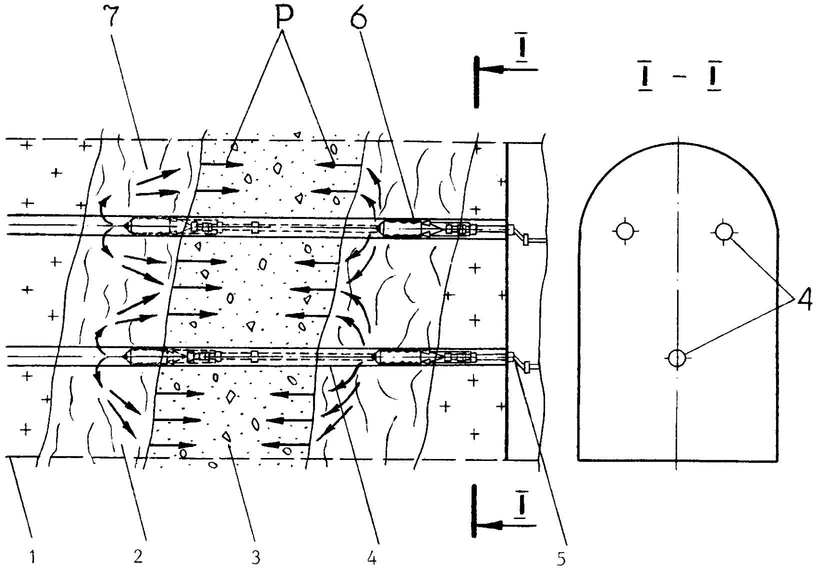

Figure 1. Rupture hydrosealing and strengthening scheme

1. Tunnel floor, 2. Fractured zone adjacent to the fault,
3. Fault filled with loose rock, 4. Grout hole,
5. Injection pipeline, 6. DAU-1 packer,
7. Direction of grout propagation.

P - force of fault squeezing

Grouting is executed with viscous-plastic clay-cement grouts developed on the basis of local clay deposits comprising 89% of a clay slurry with a specific gravity of 1230 kgf/m^3, and the rest includes cement and structure-forming additives. These grouts are characterized by good penetrability, stability to aggressive thermal water attack and rock mass movements under seismic activity conditions of the site region. Blasting operations during tunnel driving only make the grouts more compact.

For the purpose of fault hydrosealing and strenthening there has been developed new technological schemes which permit the formation of a reliable sealing barrier around a tunnel only using 2-3 underground holes drilled to the tunnel's roof. The grouting programme is always carried out by means of high-production equipment located on the surface. This technique ensures the optimum injection regimes to be attained and allows labour consumption to be reduced with a sharp increase in productivity.

Grout injection is executed employing the use of the widely known DAU-1 packers. It is carried out via a high-pressure pipeline run down the ventilating shaft or via a special borehole drilled from the surface and further through the grout holes drilled from an excavation.

Grouting results are comprehensively evaluated prior to the commencement of driving on attaining the final calculated parameters of grout injection into the hole and by means of pressurzing the barrier formed up to the calculated pressure ensuring lateral squeezing and strengthening of rupture unstable rocks.

APPLICATION

Drivage of the first pilot gallery section that pierced the Eastern Portal of the Severo-Muiski Tunnel with the approach opening of the ventilating shaft No.3 has been carried out by means of shield equipment without application of special methods. As a result in the course of fault piercing there were ingresses of the breakage products and water-saturated boulder-sand mass that repeatedly caused downtime. To eliminate these complications by-pass galleries were driven from both sides of tunnelling equipment.

Most severe conditions were expected during drivage of the last 150 metres of the gallery prior to reaching the approach opening of No.3 shaft. According to geophysical survey data the gallery would intersect a number of large faults characterized by a complex structure, high level of water abundance and rock dislocation.

To ensure safe labour conditions and reduce tunnelling time in this section advanced grouting and strengthening of the 150 m fractured zone has been carried out prior to the commencement of tunnel driving for the first time in Russian experience of tunneling under similar geological conditions.

Two horizontal 150 m and 98 m long grout holes with a diameter of 76 mm were drilled from the gallery bay in accordance with the technical scheme shown in Fig.2. On intersecting fractured zones with water inflows, drilling operations were stopped and a hydrodynamic investigation programme was carried out (Fig.3) for more precise definition of faulty strata, filtration characteristics and modifying the grouting parameters such as size and volume of the impermeable barrier [7].

This was followed by anchoring the DAU-1 packer in the hole in front of the adjacent to the fault zone, and the high-pressure pipeline, laid from the surface via No.3 shaft and along the floor of the excavation to the fact of the bay, was connected to it. Then the calculated volume of grout mixed at the surface plant was injected. The maximum injection pressure attained 24.0 - 28.0 MPa (240 - 280 kgf/cm^2) with instantaneous flow injection rate of 3 - 4 l/s. On completion of grout injection the treated zone in the hole was pressurized by water up to the calculated pressure to estimate hydrosealing reliability and quality of fault strengthening prior to the commencement of tunnelling.

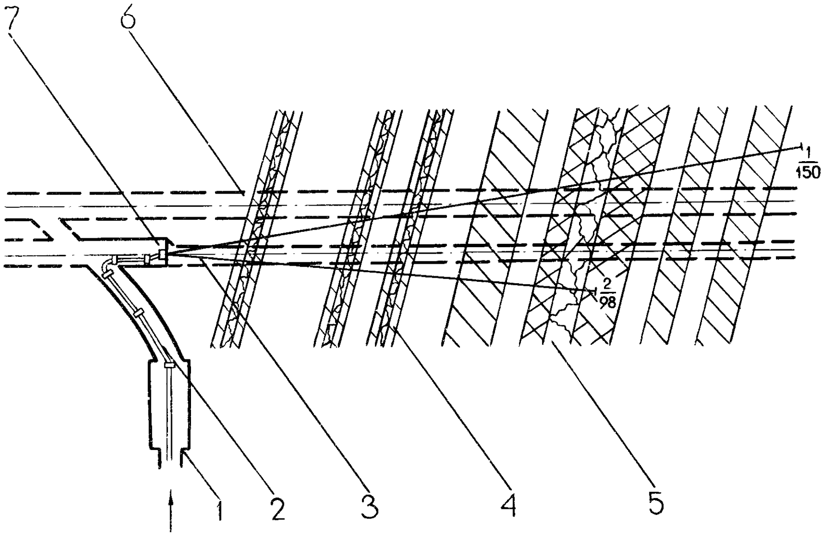

Figure 2. Advanced grouting scheme of tectonic rupture zones in tunnel and gallery driving

1. Approach opening of No.3 shaft, 2. Injection pipeline,
3. Grouting holes, 4. Fractured zone adjacent to the fault,
5. Rupture filled with loose rock, 6. Tunnel, 7. Gallery.

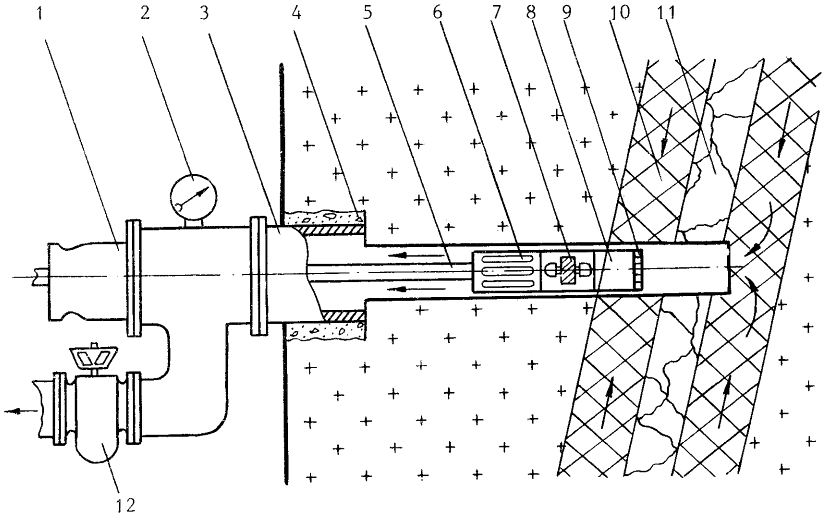

Figure 3. Scheme of hydrodynamic investigations in a horizontal borehole

1. Cap, 2. Pressure gauge, 3. Casing, 4. Cement,
5. Drill pipe, 6. Slots, 7. Spinner, 8. Sensing unit,
9. Grating, 10. Fractured zone adjacent to fault,
11. Fault filled with loose rock,
12. Sluice valve for flushing discharge.

Major parameters of the executed grouting jobs are listed in Table 1.

Table 1
Actual Grouting Data for Driving No.1 Tunnel
and Gallery in the Vicinity of No.3 Shaft

Hole No.	Hole depth, m	Water inflow, m^3/hr		Injection zone (from–to), m	Volume of grout injection, m^3
		Hole discharge	Recalculated to full gallery cross section		
1	18	20	96	6–18	69
	38	32	153	25–38	183
	55	20	96	38–55	364
	96	70	336	84–96	9
	130	20	96	108–130	259
	150	–	–	–	–
2	20	–	–	6–20	486
	42	–	–	20–42	148
	98	66	316	84–98	436

During the course of grouting there were more precisely determined boundaries of the tectonic breakage zone; its length amounted to 110 metres. While tunnelling in the interval of 18-128 m there were encountered grouted rupture zones from 1 to 8 m thick. Outlying sections represented by diversely oriented cracks with an opening from 2 to 20 cm were filled with the clay-cement material.

RESULTS

Driving in the zones of grouting has been completed without complications. Despite intensive rock breakage within these zones there has been no carry-over of water-saturated breakage products in the course of driving the Severo-Muiski Tunnel and its pilot gallery as it occurred earlier when the advanced grouting technique according to the developed method was not employed.

Residual water inflows in the treated zone did not exceed 1-3 m^3/hr. In the zones adjacent to the fault there has been fixed an intensive network of diversely oriented cracks with an opening from 2-3 to 15-20 cm has been filled with the compact grout. Unstable loose rupture rock mass squeezed during pre-cupture grout injection has been compacted and, as a result, attained the necessary stability for tunnelling.

CONCLUSIONS

There are many other examples of the proposed method in tunnelling through faults. On the whole the method has the following advantages :

- It is based on scientifically substantiated calculations of the entire process of hydrosealing and strengthening of faults.

- Cheap and efficient clay-cement grouts are used.
- Methods and technical means are employed which allow the complete initial information on the fault seepage properties to be obtained.
- Grouting is carried out on the basis of efficient technological patterns and by means of high-production equipment.
- The results of the advanced grouting are comprehensively estimated prior to the commencement of drivage.

The method makes it possible :

- To reduce by 1/3 to 1/2 the tunnelling time while driving through a fault.
- To reduce overall tunnelling costs.
- To employ more lightweight tunnel lining in the region of seismic activity.
- To gain considerable savings through the repayment of capital investments because of reducing construction time and putting tunnels into operation ahead of schedule.

It should be pointed out that the driving through such fault and tectonic fracture zones would have been possible only by freezing the entire unstable rock mass and subsequently lining the tunnel with cast-iron tubbings. The cost of such operations would be 2-3 times more than that of the advanced grouting without even taking into account the costs on lining maintenance in the region of seismic activity.

REFERENCES

1. Nasonov, I. D., Schuplick, M. N., Ressin, V. I., 'Issledovania parametrov zamorazhivania pri provedenii gorizontalnih vyrabotok', (Investigations of freezing parameters during driving), Moscow, Nedra Publishers (in Russian), 1980, p.248.

2. Dormann, A. Ja., 'Specialnie sposoby rabot pri stroitelstve metropolitenov', (Special methods during subway construction), Mowcow, Transport Publishers (in Russian), 1981, p.304.

3. Goncharova, L. V., 'Osnovy iskusstvennogo uluchshenia gruntov', (Basic principles of artificial improvement of grounds), Moscow, MGU Publishers (in Russian), 1973, p.376.

4. Volkov, V. N., Naumov, S. N., Pirozhnova, A. N., Khrapov, V. G., 'Tonneli i metropoliteny' (Tunnels and subways), Moscow, Transport Publishers (in Russian), 2nd edition, 1975.

5. 'Underground umbrella projects tunnel drive in unstable sands', Engineering Journal, Vol.2, 1976.

6. Sinarevski, A. N., 'Na tonnelah BAMa' (BAM tunnels), Metrostroy Publishers (in Russian), 1979, p.2.

7. Kipko, E. Ja., Polozov, Ju. A., Spichak, Ju. N., 'Predvaritelniy tamponazh zon tectonischeskih narusheniy pri sooruzhenii Severo-Muiskogo tonnelya' (Advanced grouting of tectonic dislocation zones during construction of the Severo-Muiski Tunnel), Shahtnoe Stroitelstvo (Mine Construction Journal) (in Russian), Vol.11, 1982, p.32.