Groundwater control during shaft sinking

E.Ja.Kipko Prof., D.Sc.(Min.Eng.)

STG Specialized Association, Antratsit, Voroshilovgrad Region, U.S.S.R.

ABSTRACT

Mine-water inflows not only threaten the miners and mining economics, but also the cost and quantity of water resources in the region. A grouting technique is now widely used in the USSR to eliminate or reduce the flow of ground water into existing or proposed mine shafts. This resulted from the development in the early 70s of a grouting method based on the integration and outgrowth of groundwater hydrology, grout chemistry and rheology, rock and soil mechanics, drilling and mining engineering.The paper gives a general review of technical philosophy and approaches with regard to grouting technology introduced and being practiced by the STG Association, the largest specialist group in the Soviet Union. A number of case histories is mentioned, together with the description of specifice aspects of shaft grouting process and design.

INTRODUCTION

Over recent years a specialized grouting organization 'STG' from the USSR has developed and refined the so-called 'Integrated Grouting Method' which is being used now for shaft sinking programmes in fissured and karst rock environment. This technique has been successfully implemented in 106 various mine shaft projects in the USSR, Hungary, Czechoslovakia, Bulgaria, Romania and has included projects related to shaft sinking up to 1600 m deep, drilled shafts with a finished diameter of up to 4.5 m and 1050 m deep, shaft repair operations and shaft reopening programmes.

GENERAL DESCRIPTION OF TECHNOLOGY

The technology developed within STG involves three major stages:

- investigation and data acquisition
- design and costing
- implementation and testing

Investigation is carried out with the specific objective of providing criteria for design and costing of the grouting programme. This will entail the determination of the grout curtain size and interlocking covers spacing, grout volume to be implaced, pressure of implacement, grout holes pattern and depth.

The process which is followed in investigation includes the drilling of one normal diameter core hole. The hole is geophysically logged on completion and flow metered. This allows permeable zones to be grouped for later grout design and injection. The objectives of in-situ testing for grout design are related to evaluation of rock voidage. hydrostatic head, hydraulic conductivity of the medium, hydraulic anisotropy.

The evaluation of the grouting environment determines the characteristics of the grout formulation required and the nature of the grouting operation considered appropriate. The grout formulation must be developed then to have:

- rheological properties compatible with the fractures, fissures and water conduits
- physical properties which will permit grout propagation through the environment under the pressures and at the temperatures which apply
- chemical properties both during implacement and long term which will be compatible with the environment and which will maintain gel strength
- set-up strengths and plasticity adequate to cope with post-grouting strata movements

Clays from the local project environment are assessed in this regard and are subjected to detailed testing in order to estimate their suitability for formulation. This includes assessment of their mineralogy and chemistry, hydration and dispersion characteristics, filtration characteristics, economics of excavation, transport and chemical conversion to establish the properties desirable.

Commonly used stabilized clay grouts consist of a chemically modified clay as the filler mixed with water of a compatile salinity and chemistry. Other reagents include the binding agents (e.g. cement, fly ash, dolomites, etc.) and structure-forming additives. Other chemicals are used to stimulate dispersion, hydration and to achieve flow and set-up properties and times. The water used in mixing is carefully controlled as to chemistry and volume and the chemicals are added to a specific schedule in order to achieve the grout slurry properties required. The specific gravity of the slurries is aimed at between 1.20 and 1.23 t/m^3, but is a property which may be varied from project to project dependent upon the pressures desired during grouting.

In implementing shaft grouting programmes STG prefer to have their mixing facilities at the surface irrespective of whether it is grouting in advance of the development of underground openings or not. While this may involve the additional cost of a conveying borehole to the grouting face, it has many advantages: avoiding disruption of development operations, removal of machinery, high pressure pipelines and fittings away from confined working spaces, acceptability of large mixing and storage equipment, avoidance of the need for personnel trained in underground working environments.

Grout placement is generally undertaken progressively moving from hole to hole, completing one defined zone after another. By flow-meter testing in advance the ungrouted transmissivity of each zone is determined (Tmax) and the client's acceptable residual inflow is converted to the desired end transmissivity (Tmin). By testing each ungrouted hole on completion of grouting in the adjacent hole plots of the declining residual transmissivity are developed. This ensures that over grouting is not undertaken on any zone or overall.

GROUTING OF FISSURED ROCK STRATA AND KARST ENVIRONMENT

Over recent years STG has completed a number of projects associated with grouting of fissured aquifers and karst environment during sinking of shafts up to 1200 m deep both through a series of 4–6 directionally drilled holes and one single hole following a spiral path around the proposed shaft. At present one similar project is in progress in Romania at the Palazu-Mare iron-ore deposit. It is related to the drilled shaft with the total depth of 650 m and final diameter of drilling 3785 mm to acommodate 2960 mm dia. casing. The problem consists in the necessity to drill the shaft through 450-m thick intensively karstified Jurassic water-bearing formation in the 50–500 m shaft section. Permeability of karst strata amounts to 40–50×10 −12 m^2 with some caverns up to 5 m in diameter. Karst voids are partially filled with saturated clay-sand material characterized by quick ground properties.

Shaft drilling in such conditions is complicated by catastrophic lost circulations, collapse of shaft bore walls, the necessity to case separate zones with additional casings, as well as the difficulty of reliably cementing the casings in such an environment.

To provide reliable sealings of karst strata, to exclude lost circulation and ensure effective cementation of casing, a pregrouting programme is being carried out in the shaft site. Grout injection is performed through 4 holes of 112 mm diameter drilled to a depth of 510 m. To achieve maximum combination with shaft drilling, grouting operations have been designed to proceed in two stages.

At the first stage karst strata is treated to a depth of 260 m simultaneously with shaft drill rig mounting. The designed quantity of grout injection at this stage equals 20,000 m^3. At the second stage the strata is treated to a depth of 500 m simultaneously with shaft drilling to a depth of 200 m. The designed volume of grout injection at the second stage is 4000 m^3.

Implementation of the grouting project for the drilled shaft PA-I at the PalazuMare deposit will ensure the simplification of shaft bore casing (Fig. 1) and considerable cost saving.

SEALING OF ABANDONED MINE WORKINGS

The problem of sealing of abandoned mine workings often arises during shaft sinking through mined-out zones or flooded mine levels. A special technique has been developed to prevent inundation of mine workings during implementation of shafting programmes.

This technique can be illustrated by a grouting project designed to control ground water inflows into a drilled shaft at the Kuybishevskaya Mine, Donets Coal Basin. The shaft bore was to traverse disused mine workings at the 270 m level while being drilled to the final depth of 550 m. In accordance with hydrodynamic testing data the opening of worked-out strata was calculated to amount to 0.3– 0.4 m. The proposed shaft had 2600 mm final diameter of drilling to accommodate 2100 mm dia. casing. Four inclined grout injection holes were drilled to a depth of 285 m. On the completion of drilling the grouting holes were geophysically logged and water tested to obtain accurate data for grouting process design.

The designed quantity of grout required to seal the worked-out strata was 11,000 m^3. Actual propagation of grout around the shaft bore was controlled by borehole acoustic television method. On the completion of grouting the shaft bore has been drilled without any complications.

RESIDUAL SEEPAGE CONTROL IN CONCRETE LINED SHAFTS

The pregrouting technique with cement grouts has been used to control ground water inflows during the sinking of the vent shaft at the Voikova Mine, Donets Coal Basin. The programme failed to be a complete success and the shaft has been sunk to the proposed depth with a residual seepage of 21 m^3/hr.

A post-grouting programme has been designed by STG to cut down the shaft inflow to standard regulations (5 m3/hr). The grouting scheme arrangement involved drilling of inclined 105 mm dia. holes through the three waterlogged sections: 24–34 m, 49–60 m and 80–104 m. The depth of grout injection holes was in the range of 15 to 30 m. Grout preparation and pumping equipment was deployed on the ground surface to inject the estabilized clay grout via a high-pressure pipeline. The grouting operations in the shaft were carried out from temporary platforms mounted at levels of 22, 47 and 75 m. The post-grouting programme allowed residual seepage to be reduced to 4.8 m3/hr.

RESIDUAL SEEPAGE CONTROL IN TUBBING LINED SHAFTS

The service shaft at the Melnikova Mine, Donets Coal Basin, traverses a porous sandstone aquifer in the section of 589–649 m. Drilling of 3 pilot holes resulted in a total borehole yield equal to 240 m3/hr at 1.7 MPa pressure head. The maximum discharge of 180 m3/hr was received from one hole. Ground water temperature was 30°C.

To ensure safe shaft sinking through the sandstone strata, freezing by liquid nitrogen was performed through 60 holes 55 m deep. When freezing was completed, shaft sinking proceeded to a depth of 614 m with tubbing lining and backwall grouting by a sand-cement mixture. At a depth of 614 m the shaft inflow increased from 3 m^3/hr up to 60 m^3/hr.

STG has undertaken the project to deal with the critical inrush of high-pressure water into the shaft excavation. Remedial operations included the construction of a reinforced concrete plug in the 610–614-m shaft section. The plug design comprised a drainage layer with a relief pipe. Ground water pressure was 1.7 MPa.

Grout preparation and pumping equipment was deployed on the surface. The back-wall zone of tubbing lining was treated with 85^3m of special clay-cement grout formulated for a low-temperature environment. Backwall grouting was followed by grouting of the drainage layer. As a result of these operations, residual seepage was cut down to 0.5 m^3/hr.

In the course of further shaft sinking the inflow at a depth of 649 m again increased to 28 m^3/hr. The waterlogged section was treated with an extra 144 m of low temperature grout which enabled the shaft inflow to be reduced to 0.4 m3/hr.

SHAFT DEEPENING

The modernization project of the Ukraine Mine, Donets Coal Basin, involved the deepening of skip shaft No. 3 from 440 m to 750 m. The anticipated inflow from this zone into the proposed shaft was 152 m^3/hr.

Three inclined grouting holes 340 m deep each were drilled from the 410-m level mine workings to treat the water-bearing layers. The arrangement of grouting holes allowed grouting operations to be carried out simultaneously with equipping the shaft for sinking. The total quantity of grout injected within a 5-month programme amounted to 4620 m^3. During shaft-deepening activities, residual seepage into the shaft did not exceed the client's specifications.

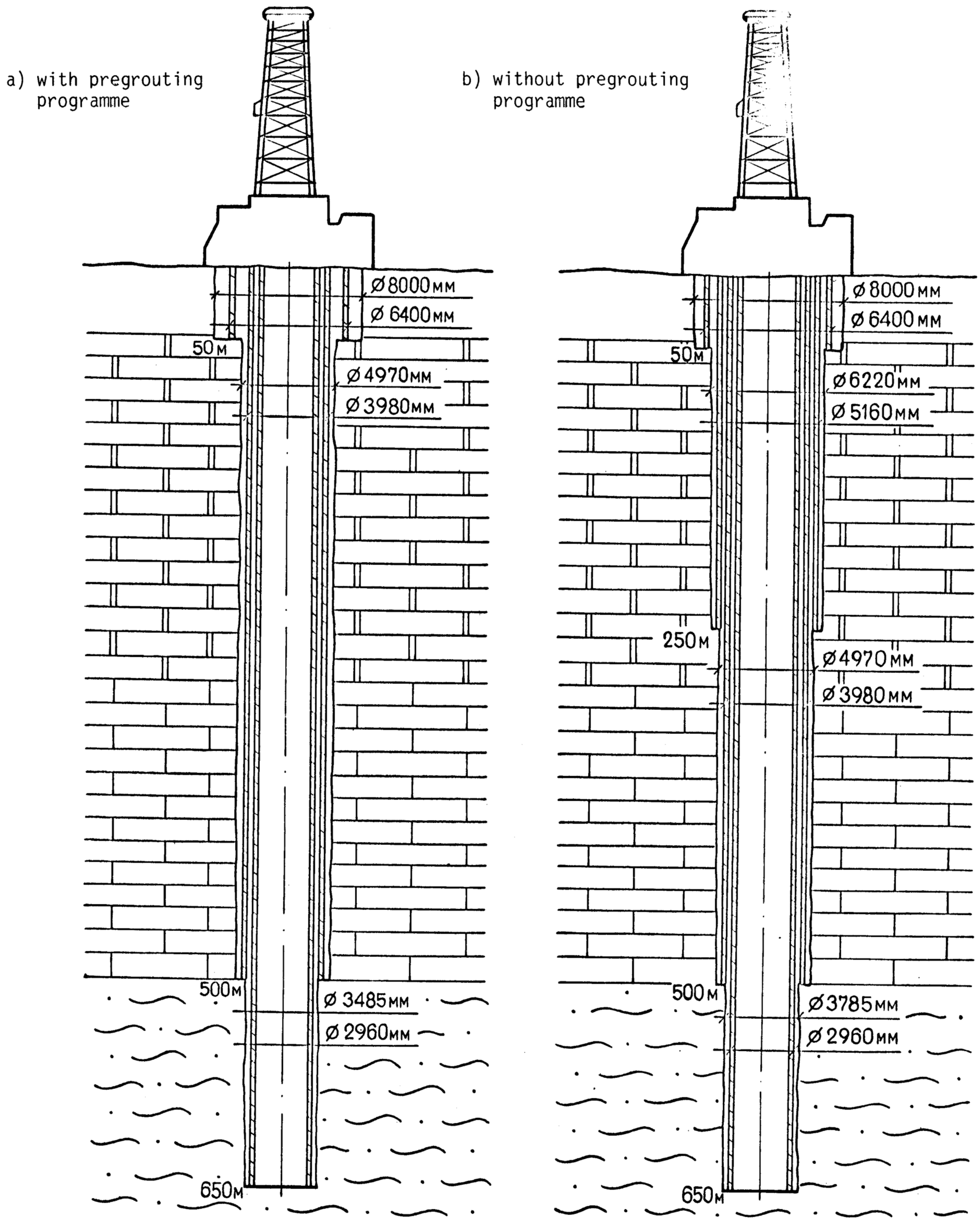

Fig. 1 Drilling and casing arrangement for shaft bore PA-I in Karst environment (Palazu-Mare ore iron deposit, Romania)