Application of Surface Pre-grouting for Shaft Sinking with Freezing In the Aquifer Formations

Yang Chunlai(1), Deng Yangfang(2), Wang Zongmin(2)

(1) Researcher, China Coal Scientific & Research Institute
(2) Senior Engineer, Overseas Projects of Zhengzhou Coal & Electricity Group
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ABSTRACT
Some special techniques could be taken into consideration in case of sinking shaft and/or slope construction in the aquifer formations. As well known, freezing method is a prevalent technique used for the shaft construction in alluvium. In consideration of the unstable aquifer formations in Chinese coal mines, freezing method is always adopted in constructions in the aquifer alluvium and surface pre-grouting method in the rock-bed formation in order to make shaft-sinking project a success. This Paper introduces the technology of surface pre-grouting for shaft sinking with freezing in the aquifer alluvium formations. So far, the freezing method has been adopted in constructions of up to 500 vertical shafts in China, which produces a total length of 80 km, and the pre-grouting method has been applied in more than 150 vertical shaft sinking projects. The maximum depth of freezing sinking is about 702m, and the depth of surface pre-grouting reaches more than 1000m in China.

INTRODUCTION

Freezing method

Freezing method in shaft sinking was invented by F.H. Poetsch in 1883. Its essential feature is the solidifying, by freezing, of water bearing ground in which the shaft is sunk. The freezing is sometimes continued into water bearing rock. This method has been widely used for 50 years in China.

To prepare for the freezing, a series of equally spaced boreholes are drilled on a concentric circle enclosing the site of the shaft. Heat is removed from the ground via probes placed into the boreholes. The probe itself consists of an external pipe, 50-150mm in diameter, closed at the lower end and containing an open-ended inner tube of slightly shorter length. The inner tube may vary between 20-75mm in diameter. The freezing tubes are connected with two circulation mains, in such a manner that cold brine may be pumped down the inner tube and allowed to return along the annular space between the two tubes and thence through the collection main back to the refrigeration plant. Here it is pumped through a chiller—normally a shell and tube heat- exchanger—and is cooled down again and then delivered via a distribution main back to the inner tubes of the probes. The coolant is therefore confined in a closed, recirculatory flow path. Industrial refrigeration plant is required to cool the brine. Abstracted heat is dissipated into a nearby watercourse if available, if not then into the atmosphere by forced-draught cooling towers or evaporative condensers.

The effect of circulating a coolant through the complete system is to produce around each column long pencils of frozen strata which increase gradually until, when the merge, a circular barrier of frozen ground is formed, known as the ice wall.

During excavation refrigeration is maintained, generally in excess of the level required to offset heat transference from the warmer strata surrounding the shaft.

In 1955, the freezing method was introduced to China from Poland and first applied in the Linxi Mine ventilation shaft of the Kailuan Coal Mining Bureau. 50 years have past since then. During the past 50 years, areas such as professional research, equipment, technology, academy and construction level have witnessed rapid development. Till now, the freezing method has been applied in the construction of up to 500 vertical shafts in China, which produces a total length of 80 km. The Dingji Mine of the Huainan Coal Mining Bureau in Anhui province that has already been constructed holds a freezing depth of 565m, among which the thickness of alluvium is 520m. The Guozhuang Mine in the Juye Mining area of the Shandong province that is still under construction is expected to hold the deepest freezing depth of 702m, among which the thickness of alluvium is 570m.

Today, freezing method has become one of the most important special methods in the construction of underground buildings including shafts in the complex and unstable aquifer formations of Chinese coal mines due to its high reliability and good security. In recent years, freezing method has become popularized in construction projects such as Metro and city communication.

Grouting Method

Grouting method is the primary technique adopted for constructing shaft through water-bearing bedrock strata (WBBS). Grouting refers to inject cement, clay or chemical liquid grout into crannies or water-eroded caves within WBBS by means of mechanical methods. The purpose of grouting is to block water channel and assure no water there during shaft construction.

Grouting was first introduced by a French, Charies Berigng, to construction projects in 1802. UP to now, it is of 200 years' history.

Chinese coal mining industry (CCMI) started ground pre-grouting (GPG) and working surface pre-grouting (WSPG) from 1950s. Lots of new materials, techniques, and specialized equipment for grouting have been developed since 1960s. Especially in recent two decades, CCMI make great process in research and development of new grouting techniques. Some of them have reached the advanced level.

Ground Pre-grouting

GPG is applicable to construct shafts that pass through either relatively thick WBBS or relatively thin WBBS but with more layers.

So far CCMI has built up more than 150 vertical shafts by means of GPG. The maximum depth reaches 1,000 meters.

GPG could be grouped into normal drilling ground pre-grouting (NDGPG) and directional drilling GPG when it is classified by drilling techniques, or cement grouting and clay-cement grouting by grout materials.

Vertical shaft ground pre-grouting (VSGPG) for normal drilling

Usually boreholes scatter along the circle of a shaft, but outside a excavated diameter. Boring machine should drill down vertically.

a. Number of grouting holes

Considering geological features of WBBS in China, every vertical coal shaft needs 6-8 grouting holes.

b. Borehole verticality

Grouting holes may have slight angle of 0.3% through alluvium and 0.6% through bedrock. Therefore, we use turbinate clinometers to examine gradient of boreholes during drilling process. Whenever a borehole is found with an angle larger than the designed tolerance level, it should be corrected immediately.

c. Type of grouting

In China, the prevailing type of grouting is pressure grouting. Pressure grouting is a method by which a grout pump squeezes grout into grouting holes to fill up crannies. The characteristics of pressure grouting include speedy grouting, high pressure, high intensity of grout fill-up, greater strength of after coagulation, and capability of entering cracks.

According the stage completion order, grouting is further classified into downward stage and upward stage completion. Downward stage completion is adopted in normal grouting.

d. Height of each grouting stage

The height of each grouting stage is determined by factors of thickness of WBBS, level of weathered surrounding rocks, reliable end grout position, and capability of group pump. The appropriate height of grout is around 10 meters during heavily broken stratum, 15-25 meters during broken stratum, 25-35 meters during hard rocks, and 35-80 meters for regrouting.

e. Effective diffusion of grout

Many factors influence the effective diffusion of grout. Normally grout diffuse 6-9 meters effectively.

f. Grouting pressure

Grouting pressure is the source of power for grout to enter strata. High pressure leads to farther diffusion. Low pressure leads to insufficient diffusion and negatively influences the effectiveness of water block.

The data collected from practice indicate that the maximum grouting pressure is 2-2.5 times of the static water pressure (SWP) when the width of cracks is less than 10mm, and 1.6-2.0 times of SWP when the width is larger than 10mm.

g. Amount of grout

The amount of water required for VSGPG is computed with following function:

$$V=A\pi R^2 Hn\beta$$

Where,

V = the amount of grout used in each stage of completion for each grouting hole

A = parameter of grout consumption, generally ranging from 1.2 to 1.5

R = effective grout diffusion radius

H = height of grout section

N = percentage of cracks in rocks

β = parameter of grout filling, generally ranging from 0.7 to 1.0

h. Density of grout

Generally speaking, higher density grout is applied at the beginning and lower density one at the ending period. However, for each stage of grouting, high density grout should follow low density one.

i. Ending amount of grout

When each stage of grouting approaches to the end, grout pumps should keep outflow at 50-60t/min for 20-30 minutes.

Introduction of Clay-cement Grouting

The usage of clay-cement grout (CL-C) in VSGPG in China is of almost 20 years' history. CL-C has been applied to more than 70 shafts and dominates grout materials in almost all coal VSGPG in recent years. CL-C differs from purely cement grout in that it could be injected faster but at lower cost and with higher quality. Among those shafts

that use CL-C, 92.3% of them have residual water less than $10m^3/h$ when starting drilling, and most of them less than $5m^3/h$.
CL-C is composed mainly of clay (89-90%), cement (8-10%), chemical additive (1-2%) and water. It's a type of plasticized sticky liquid with distinctive characteristics, such as good injectablity, relatively high waterproof ability and long term inoxidizability.
Technical requirements of CL-C grouting may refer to normal ground pre-grouting techniques with respect to the layout of boreholes, assembly of drilling tools, drilling technology, deviation monitoring and correction, grouting equipment, grout transportation system, and grout termination.
Upward stage completion of grouting is performed in the case of CL-C grouting. The height of stage ranges from 40 to 70 meters.
Experience indicates that ending injection pressure is twice of static water pressure and plus 3-5 Mpa (See the following chart).

Depth of Grouting (m)	<300	300—500	500—700	>700
Injection Pressure (MPa)	7—9	8—14	10—18	18—25