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A new technique for grouting old mine workings

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ABSTRACT

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Models related to the implacement of grout covers in zones of abandoned mine workings are discussed and methods of design, grouting equipment, processing methods and new grout mixtures that have been formulated for mined-out strata described. A number of case histories are presented to illustrate the application of the techniques developed to mining and civil engineering projects.

Introduction

The rapid growth of the mining industry is necessitating the development of advanced techniques to protect civil and mining engineering projects from the impact of abandoned mine workings.

Abandoned mine workings can often be encountered during construction of mine shafts or buildings and other surface structures. Shaft drilling through such strata may result in major losses of circulation liquid which lead to serious problems and increased costs.

In addition, buildings and other structures within the zone affected by abandoned workings may suffer from ground subsidence. This causes problems such as fractures which can seriously affect their stability.

To overcome this problem the grouting of abandoned mine workings is a prerequisite for the increased technical and economic efficiency of mining and civil engineering projects.

The Specialized Agency on Grouting and Geological Services (STG) has developed a novel technique for treating the abandoned workings based on comprehensive engineering analyses of the entire process, application of specialized instrumentation, processing methods and visco-plastic grouts. The basic constituent of these grouts is the waste product of dolomite processing.

Theory and job planning

Analytical studies of sealant emplacement processes under various mining and geological conditions resulted in the development of two numerical models (for forced flow and free flow of grouts). These describe the flow of visco-plastic grouts in mined-out rock strata and provide an explanation of rheological and structural-mechanical properties of grout; hydrostatic pressure; dynamic changes in sealant geometry, etc. The analytical studies were used as a basis for the development of specific methods designed to carry out comprehensive engineering analyses of all parameters involved in the emplacement process.

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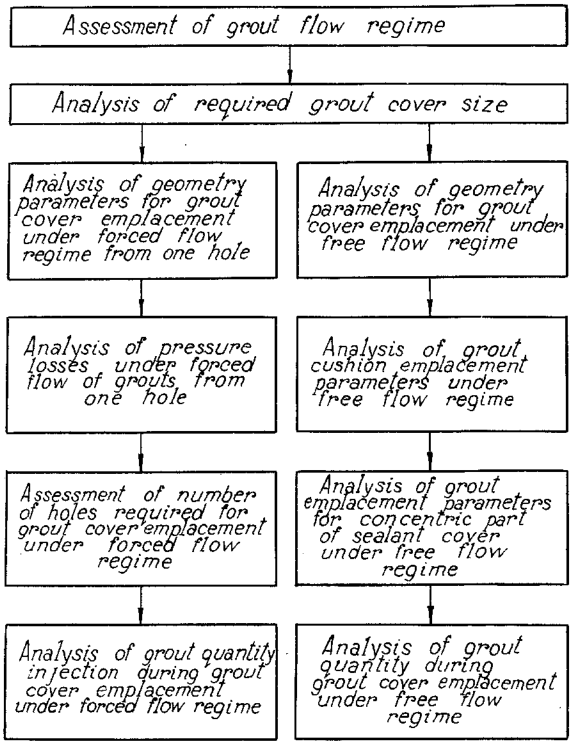

Fig. 1. Flow chart or designing grouting programs for abandoned workings.

The method developed for grouting mined-out strata using a forced flow of grout takes the relief into account. For free-flowing grout, the design is based on a two-stage, portional injection process; during the first stage a pillow sealing the roof and the floor of a working is emplaced, concentric covers are then formed around it.

The use of a two-stage, portional injection process makes it possible to form grout covers with a specific geometry.

The principal stages during an engineering analysis of sealant formation in abandoned workings are shown in Fig. 1.

Tools and instrumentation

Grout injection holes drilled to intersect old workings become considerably wider in the zone of induced fracturing over worked-out strata. To ensure safe separation of grouting holes under such conditions, STG developed the DAU-1U packer. Owing to the special design of the cone die mechanism, the packer achieves a high operation efficiency, even when the development factor of a well is 2. At higher development factors, a special device, Model DAU-1UM, is used that allows "dead" packing in practically any environment.

The major part of the initial data required for planning a grouting program is obtained during flow metering and pressure build up testing which are undertaken in exploratory and grouting holes.

Flow-meter tests are carried out using the DAU-3 probe, designed by STG. This enables testing to be conducted in a broad range of hydrogeological conditions.

A wide variety of data can be obtained by pressure build up testing. This technique demands accurate and detailed monitoring of changes in water level in a well. At shallow depths and slow rates of water level change this is easily solved by using a downhole contact device.

When intersecting karst, large open fissures or old workings, high rates of water level change have to be monitored during testing. Under such conditions, the above-mentioned devices do not provide the required accuracy and response. This necessitated the design of a new instrument for continuous monitoring and registration of water level changes downhole. The DAU-4 electronic level-meter provides highly accurate measurements at flow rates up to 2 m/s with data displayed and plotted in parallel. A general scheme of the instrument is illustrated in Fig. 2.

Grout mixtures

A wide range of clay–cement or clay–fly ash grouts formulated by STG can also be used as sealants in abandoned workings. If,

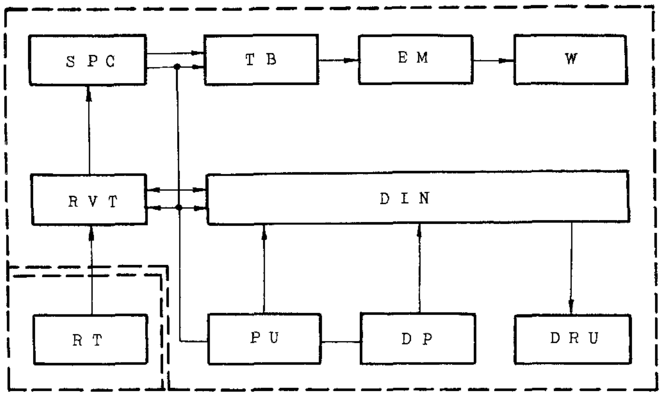

Fig. 2. Generalized diagram of electronic level-meter, model DAU-4. *RT* = resistance transducer; *RVT* = resistance voltage transducer; *SPC* = sampled data-phase control, *TB* = thyristor block; *EM* = electric motor; *W* = winch; *PU* = power supply unit; *DP* = discrete pickup; *DRU* = data recording unit; *DIN* = data interpretation unit.

during a project, a large opening or underground voids are encountered, this could involve a considerable amount of grout and a request may then be made to substitute this with cement, which is expensive.

A series of laboratory studies has been carried out to find a solution to the above-mentioned problem. This resulted in the formulation of cost-effective grouts based on the waste from dolomite processing. Fine dolomite material from the dust collectors of rotary kilns is used as a basic constituent of the new grouts.

Three types of grouts containing no cement have been developed:

(1) dolomite–silicate grouts;
(2) clay–dolomite–silicate grouts;
(3) dolomite–soda grouts.

The basic properties of these grouts are listed in Table 1 and Figs. 3–8.

Dolomite–silicate grouts have a satisfactory rheology and strength. A rapid increase in strength is characteristic of dolomite–silicate grouts, which means that they can be used in complex hydrological environments with high transmissivity.

Clay–dolomite–silicate grouts demonstrate satisfactory geo-technical parameters and have a high shear strength, which means that they can be used for inclined fractures by applying a series of grout layers in a free-flow regime.

Dolomite–soda grouts have reliable propagation and rheological characteristics; and sufficient geo-technical parameters and strength. In addition, they are cheap, which

TABLE 1

Composition and properties of dolomite-based grouts

Grout composition	Specific gravity (10^4 N/m^3)	Plastic strength (10^2 Pa)				
		Minutes			Days	
		1	10	240	1	30
Dolomite–silicate grouts	1.52	1.5	64	5681	10000	10000
Clay–dolomite–silicate grouts	1.32	2.5	12	133	1413	4178
Dolomite–soda grouts	1.69	4.7	8	168	205	10000

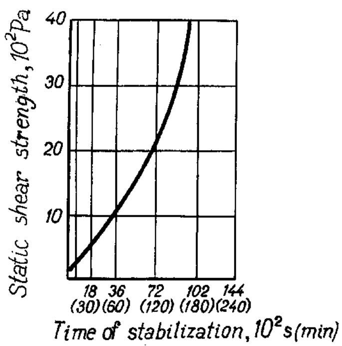

Fig. 3. Static shear strength of dolomite–silicate grouts versus time of stabilization.

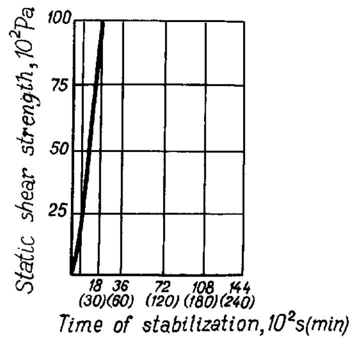

Fig. 4. Plastic strength of dolomite–silicate grouts versus time of stabilization.

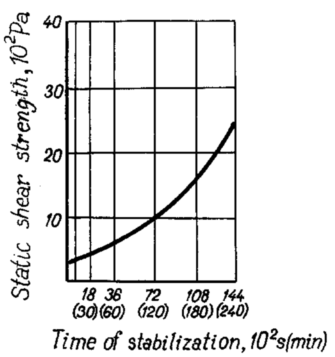

Fig. 5. Static shear strength of clay–dolomite–soda grouts versus time of stabilization.

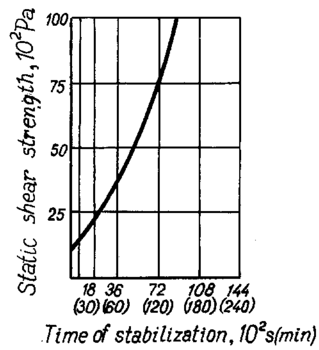

Fig. 6. Plastic strength of clay–dolomite–soda grouts versus time of stabilization.

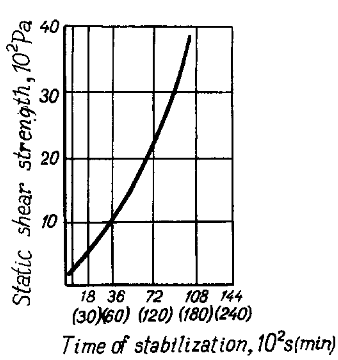

Fig. 7. Static shear strength of dolomite–soda grouts versus time of stabilization.

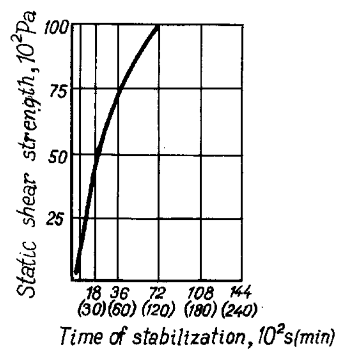

Fig. 8. Plastic strength of dolomite–soda grouts versus time of stabilization.

makes them the most preferable to use.

On the basis of the given characteristics, dolomite–soda grouts can be recommended for solving a wide spectrum of technical problems, including grouting goaf areas and zones of artificial fracturing over them; and sealing drifts, inclines, shafts etc.

Methods

A versatile grout mixing line has been developed to cope with the demand for large quantities of sealant (Fig. 9). Its capacity amounts to 300 m^3/day and the arrangement allows the preparation of both clay–cement and the above mentioned non-cement grouts in a broad range of formulations.

Depending on the hydrogeological conditions present various processing methods can be used to obtain reliable grout treatment of drifts and inclines.

Figure 10 illustrates a grout injection method for treatment of abandoned workings with highly permeable zones of induced fracturing above and using a free-flow regime. The method entails assembling a hidden well casing that covers all the zone of induced fracturing. The well casing is perforated at the level of the old workings. The DAU-1U packer is then lowered downhole to the top of the well casing to seal the well and inject the grout. In instances where rock strata encountered in the roof of old workings are not intensively fractured the second grout injection method is recommended (Fig. 11).

The third method (Fig. 12) can be applied when injecting sealant in a free-flow regime. This entails assembling piping down to the depth of the mine working and pumping grout through the piping.

Case histories

In 1984 grouting of mined-out strata in coal seam K3 was undertaken at Kuibyshevskaya Mine (Donets Coal Basin), U.S.S.R. during the drilling of a ventilation shaft.

The shaft drilling program was confronted with complex hydrogeological conditions. Old workings belonging to coal seam K3 pre-

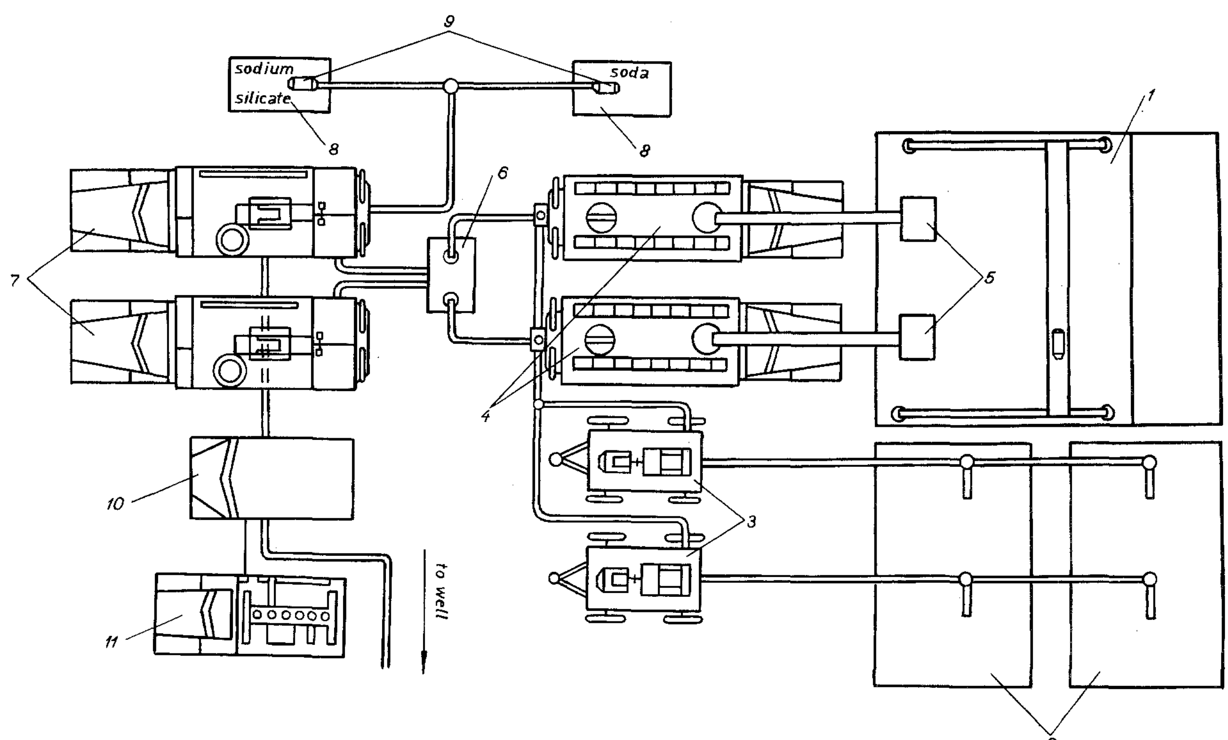

Fig. 9. Multi-purpose arrangement of equipment for grout mixing and injection. *1* = clay slurry preparation plant; *2* = 250 m^3 slurry holding tanks; *3* = transfer pumps; *4* = cement-mixing truck; *5* = hoppers; *6* = 1 m^3 tank; *7* = grout pump truck; *8* = 4 m^3 tanks; *9* = pump; *10* = manifold truck; *11* = monitoring truck.

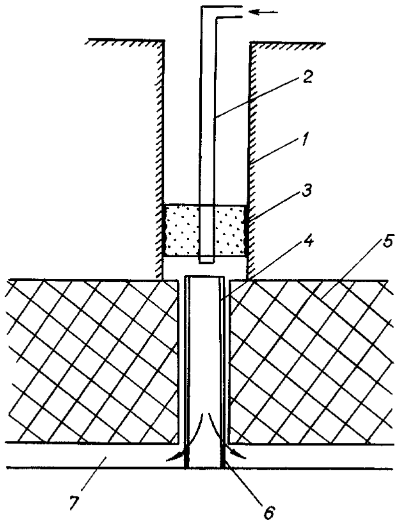

Fig. 10. Grout injection method for old workings with overlying zone of intensive fracturing. *1* = borehole; *2* = drill pipes; *3* = packer; *4* = well casing; *5* = zone of intensive fracturing; *6* = perforation; *7* = old working.

sented major problems because, if a shaft bore cut through them, this might result in lost circulation and the collapse of the borehole walls.

To eliminate any potential complications, a pre-grouting program had been planned for the shaft drilling project. The geology of the site was Carboniferous sediments with overburden. The dip of the old working was 16° with an azimuth of 330°.

The mined-out thickness of coal seam K3 in this region was 1.2 m. Fractured sandstone,

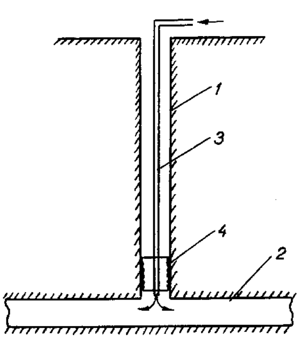

Fig. 11. Grout injection method for old workings with competent roof strata. *1* = borehole; *2* = old working; *3* = drill pipes; *4* = packer.

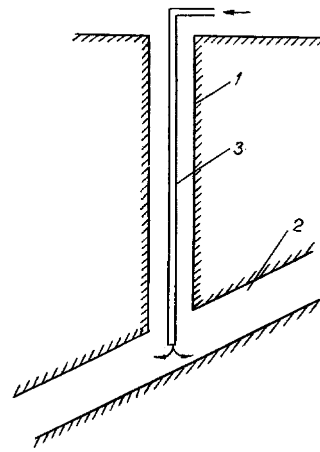

Fig. 12. Grout injection method during a free-flow regime. *1* = borehole; *2* = old working; *3* = drill pipes.

37 m thick, was encountered in the roof with a 3 m thick layer of mudstone in the floor of the working.

From the total of six grouting holes drilled, four were used for grout injection. Detailed information about the old working was obtained during hydrogeological testing and geophysical logging, which included:

(1) flow-meter tests;
(2) pressure build up tests;
(3) acoustic tests;
(4) inclinometer tests;
(5) caliper tests.

Interpretation of downhole test data produced the results given in Table 2.

An induced fracture zone was detected in the interval between 202 and 272 m, formation of which was originated by caving.

Clay–dolomite–silicate grout was selected for the project. The grout mixing plant in-

TABLE 2

Downhole test results

Grouting interval (m)	Location of fractured zone and hole number	Designed opening of fractures (m)
252–272	272.8–273.8 (no. 1)	0.31
	270.8–271.8 (no. 3)	0.30
	272.4–273.0 (no. 4)	0.28

cluded: a clay stockpile; clay recovery, disaggregation and hydration equipment; clay slurry storage tanks and grout transfer and injection pumps; and process monitoring equipment.

The DAU-1U and DAU-1UM were employed for reliable separation of grout treatment zones in the holes. Originally it was calculated that 10530 m^3 of grout would be required to seal the old working, but on completion of hydrodynamic testing this amount was recalculated at 11730 m^3. Sealant emplacement proceeded using a free-flow regime and portional injection method. The volume of each portion varied between 3 and 60 m^3. The actual volume of grout injected was 11560 m^3.

Grouting operations allowed shaft drilling at Kuibyshevskaya Mine to be completed without any complications. Drilling of the shaft bore proceeded successfully and no loss in circulation was detected. This helped to give a considerable time saving.

The grouting program aimed to seal old

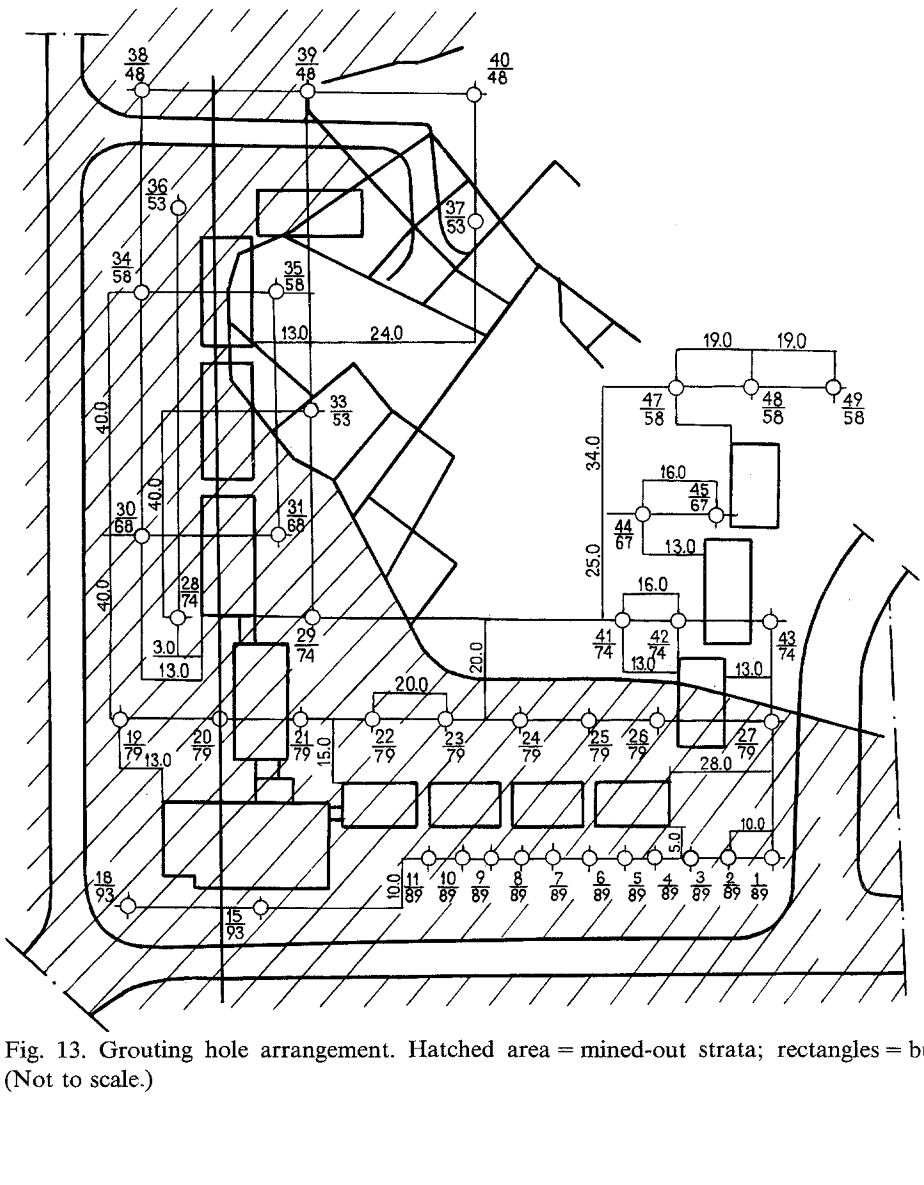

Fig. 13. Grouting hole arrangement. Hatched area = mined-out strata; rectangles = buildings; o = grouting holes. (Not to scale.)

workings encounted in rock strata under 12-storey apartment blocks in Lisichansk, Ukraine is another example of the application of the new technique. The building was constructed without regard to safety; which lead to foundation movements, wall fracturing etc. Evacuation of residents from the building had even been considered. A grouting program to neutralize the impact of old workings was accepted as a protective measure.

The old workings belonging to coal seam K8 had dip angle of 16°, with an azimuth of 160–175°. The limestone layer encountered in the roof of the old workings was not strongly affected by caving. The average thickness of the coal seam K8 extracted was 1.1 m, and the depth of this bed in the problematic area varies between 45 and 100 m.

STG prepared a project report outlining a drilling program of 49 grouting holes spaced around the building taking into account a 15 m long protective zone (Fig. 13).

Analysis showed that grout pillow formation would occur in free-flow regime using the portional injection procedure.

The amount of each portion varied between 2 and 125 m^3. The total quantity of grout required for the program was 19740 m^3.

On completion of the grouting program 19697 m^3 of grout had been injected into the critical strata. Results obtained during drilling control- and observation-wells showed the high quality of grouting operations. Subsequent monitoring showed that subsidence and deformation processes had completely stopped.

It should also be pointed out that the above-described technique can be successfully used to treat karst zones encountered at shallow depths. For instance, intensive development of karstic voids underlying a residential area in Karlo-Libknehtsk (Ukraine) resulted in deformation of the foundations and ruptures in the wells of houses. Karst zones occurred at depths between 5 and 15 m and the aforementioned technique was employed during restoration activities. When the job was completed no further deformation was ever detected.

Summary

This new technique of grouting abandoned mine workings can provide an integrated solution for the problems associated with the safety requirements of civil and mining engineering projects. These include:

(1) Inflow prevention in mine shafts intersecting old flooded workings.

(2) Exclusion of major losses in circulation during shaft drilling into mined-out strata.

(3) Formation of strengthening supports under structures affected by old workings so that it is possible to carry out construction in undermined areas.

(4) Sealing of abandoned shafts etc.