Exclusion of Residual Water Manifestations in Mine Workings

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ABSTRACT

Post-cementation technique is the most wide-spread method to exclude water makes in mine workings. Nevertheless, the conventional technique of post grouting is lacking a sufficiently developed theoretical base, and in the main, it is a set of practical patterns and procedures that will depend both on geological-mining conditions and on the experience and skills of personnel. As a result, the application of unrational grouting process patterns leads to a considerable increase of expenditure for the construction and maintenance of permanent workings. The paper tries to reconsider the conventional approach to post-grouting programs planned for the mine shafts.

INTRODUCTION

The origin of residual water manifestations during the construction and at the operation phase of underground structures may be attributed to technogenous permeability of rocks. As is generally known, redistribution of stresses develops in the rock strata intersected by an underground opening. This will be dictated by the primitive stressed state, configuration and location of an underground opening, excavation technique, mechanical properties of lining and rocks, geological and structural features of rock occurrence.

The modified stressed state is characterized by the formation of zones with artificial (technological) inhomogeneity the origins of which can be different dependent on the type of mining activities. For instance, in the course of drilling and blasting operations the formation of inhomogeneity is bound up with fracturing, during rock freezing it results from the process of ice formation, and in constructing openings by internal blasting technique (with a camouflet charge) it arises from the compaction of plastic rock in surrounding strata.

In rock mechanics a theoretical approach to strata with artificial inhomogeneity is associated with the concept of technological influence. A zone of technological influence is defined as a portion of rock strata within the boundaries of which the properties described by an average value of a certain criterion A become different from the properties of the rest part of strata. From the point of view of mechanical state the zone of technological influence can represent consolidation or lost strength zone, or be a combenation of the first and the second. Separating this region as a disturbed rock zone (D.R.Z.) let us examine its interrelation with the process of grout cover formation while sealing off residual seepages in the mine shafts sunk by drilling-and-blasting methods.

CONVENTIONAL APPROACH

Conventional techniques of residual seepages control foresee the formation of sealing covers directly behind the lining, i.e. in the D.R.Z. For instance, the most widespread post-cementation technique is implemented by drilling through permanent lining series of horizontal holes 0.25 to 3-10 m long with subsequent injection of cement grouts. The water bearing section of a shaft is subdivided into separate "tiers" (stages) that will be 15 to 20 m long. In each tier the holes are arranged into rows which are spaced at a distance of 1.5 - 2.0 m between each other. The spacing between the holes will be selected as one hole per 1-3 sq. m of permanent lining. The grout hole pattern can follow staggered arrangement, parallel rows or spiral path. To prepare cement grouts various types of cement can be used, in many cases in combination with suitable fillers and reagents.

Let us note the major drawbacks to this method:

- "blind" systematic treatment of backwall rock zone with unpredictable course of grouting,
- large quantity of repositionings of suspended equipment in the shaft,
- necessity to open shaft lining with numerous holes and accomodate shutting fixtures,
- placing too much equipment for carrying out grouting job in constricted conditions of a shaft bottom,
- low rates of grout injection due to frequent technological stoppages caused by grout intrusions via control holes and lining joints.

Further, it should be pointed out that the formation of grout covers in close proximity to the lining precludes from applying high injection pressures due to limitations dictated by the strength parameters of lining material (in practice from 0.5 to 4.0 MPa). But in this case the process of sealing very often comes mainly to redistributions of water flows in conductivity channels of backwall zone.

THEORETICAL PREMISES, DISCUSSION, SUMMARY

Let us briefly describe the strained condition of the solid in the neighbourhood of extended underground opening of a curcular cross section. In accordance with the stress-strain model of rockmass response three characteristic zones arise, in the general case, around an underground opening (Fig. 1),

I - zone of ruin failure (residual strength). Due to failure the rock encountered in this zone transformed into nearly loose mass.

II - zone of post-failure condition. This zone is charateeized by strength and deformational inhomogeneity since the rock is affected non-uniformly, from a maximum failure at the internal boundary $r = r_p$ to unbroken state at the external boundary $r = r_n$.

III- zone of pre-failure condition. Maximum resistance of the rock has not been achieved. Volumetric changes have a double character and at the boundary $r = r_n$ are practically equal to zero.

It is obvious that the zones I and II will be the most critical ones as for non-elastic strain response.

For an ideal brittle solid on condition that $\sigma_{r_n} = \sigma_{r_q}$ the size of zones I and II can be defined from the equation

$$r = \left[\left(\frac{2q - \sigma_{сж}}{2(1+\lambda)} - \frac{2\sigma^{\circ}_{сж}}{2\lambda}\right)\left(\frac{2\lambda}{2\lambda P + \sigma^{\circ}_{сж}}\right)\right]^{\frac{1}{2\lambda}} \qquad (1)$$

where $\sigma_{сж}$ - residual strength, MPa,

λ - coefficient of lateral thrust,

P - reactive resistance of lining, MPa.

One should point out the following. The new stress field around an excavation is charaterized by the concentration of stresses in the proximity to exposed surfaces. The maximum stress concentration exists within the excavation outline or extends into the strata that can be observed, for instance, in the neighbourhood of workings excavated by drilling-and-blasting technique. In both cases the concentration of stresses is rapidly fading away while regressing from the excavation into the strata.

Even after installing sufficiently rigid lining the processes of non-elastic displacements of the surrounding strata and its mechanical failure will not be stopped and result in further fracturing under the influence of extraction and development activities. This is especially characteristic for hydrostatic, corrosive environment or complex tectonic structures.

It is known that the stability of intersected rock strata can be increased by the injection of binding agents. The effect of strengthening will be that owing to filling of voids and fissures acting static and dynamic forces generate more uniform stress field with simultaneous decrease in the number of stress concentration zones. Such an effect as an additional one, can be achieved during rock treatment by grout injection.

However, the formation of grout covers in the D.R.Z., that is the most critical one in relation to non-elastic deformation, will not provide a long-lasting effect. As a result, the expenditures on upkeeping and repair of mine workings remain very high.

Summing up one may make such a conclusion:

- the formation of grout covers in the D.R.Z. (described by the radius r_n) does not correspond to an up-to-date approach to the processes of sealing the rock strata by grout treatment, and does not provide effective upkeeping of mine workings in the course of extraction and mine development activities,
- selection of an optimum arrangement pattern for injection holes based on an accurate analysis of mining and geological conditions of the site together with a purposeful control of rheological and mechanical parameters of injected grouts are efficient means to form grout covers of designed geometry and location. These means can be

advantageously applied for residual seepages control in an attempt to improve conventional schemes and approaches.

POST-GROUTING WITH DIRECTIONAL HOLES EXTENDED THROUGH THE TOTAL THICKNESS OF WATERED ZONES AS A BASIC SCHEME

Basing on the methodology of Integrated Grouting Technique /2/ the STG Company has developed approaches and design procedures in post grouting of mine shafts. Grouting procedure illustrated by Fig. 2 involves the execution of drilling and injection operations in a watered section from one single level in the shaft excavation. The length of grout holes will depend on the thickness of water bearing layers, type of fracturing and specification of the equipment. The impregnation of watered zones is carried out at a calculated distance from the walls of an excavation placing high-capacity grouting equipment on the ground surface. This scheme aims at providing a long-lasting sealing curtain of designed configuration and extent.

The required size of grout covers is designed with the proviso to ensure grout stability in water bearing fissures under hydrostatic pressure attack;

$$R = \frac{\delta P_K}{2\tau} \qquad (2)$$

where δ - fissure width, m,
P_K - hydrostatic pressure head, MPa,
τ - dynamic shear strength of grout, MPa.

The angle of drilling directional holes is defined with the proviso to intersect the watered section behind the zone of disturbed rock (D.R.Z.);

$$\alpha = \frac{R + r_{\Pi}}{H_o + (R + r_{\Pi} + r_{\text{в}})\, tg\,\beta}, \qquad (3)$$

where H_o - distance from hole collar to the roof of separated section in the shaft axis, m,

r_B - excavation radius of a shaft, m,

β - rock dip angle.

The length of directional holes in such case can be determined from the equation;

$$\ell = \frac{H_o \pm (R + r_n + r_B)\, tg\, \beta}{\cos \alpha} + \frac{M}{\cos(\alpha \pm \beta)} + K \,, \qquad (4)$$

where M - thickness of separated watered section, m,

K - amount of hole deepening into water resisting layer (0.5 - 2.0 m).

Drilling and injection sequence will be determined taking account of the thickness and type of an aquifer, direction and yield of ground water attack. Two patterns can be most rational for a post-grouting job;

- priority drilling of holes in the stage and successive grout injection (Fig. 3),
- simultaneous drilling of holes in the stage and subsequent grout injection into each hole or combining them in series (Fig. 4).

The first pattern can be applied in the presence of several fracturing networks, fault zones or large water inflows. The second one is applicable for the conditions of uniform fracturing and porosity.

The number of grout injection holes is designed by graphical analysis with the proviso that grout covers are to interlock behind the D.R.Z. outline (See Fig. 3 and 4).

Design procedures include calculations of grout injection pressure, selection of grout formulation with suitable rheological and strength parameters for the planned geometry of injection holes. Our experience shows that the use of stabilized clay grouts will be, in most cases, the optimum engineering solution. Such grouts, being sufficiently plastic bodies, will not only ensure high sealing effect but also contribute both to more uniform distribution of static and dynamic stresses in the rock strata and increase strata resistance to tensile stresses. The latter is very important when an underground excavation is exposed to mass blasting operations during ore extraction.

The preparation and injection of grout in all cases is performed by the equipment located on the ground surface. Grout injection is executed either on the total thickness of an aquifer by packering its roof at the designed distance from the shaft ($R + r_{\Pi}$) or several zones can be Such zones are revealed in the course of drilling and hydrodynamic testing.

When the formation of an interlocked grout curtain is completed there will be created a sandwich structure in the system 'rock strata - underground excavation' in which interrelated zones of disturbed and grouted rocks behave as a flexibility element of the permanent lining.

S U M M A R Y

Flexible and broad application of the aforementioned approaches during implementation of post-grouting programs can help in efficient and guaranteed ground treatment under varying hydrogeological and mining conditions with reasonable cost data. The grouting scheme aimed at obtaining conductivity resistance and increasing loading capacity of the lining contribute also to simplification and higher rates of post-grouting operations.

Following this logic one may state that if the need in post grouting arises, design of post-grouting programs should be based on the following considerations;

- neautralization of hydrostatic and corrosive ground water attack on permanent lining and mining equipment,
- strengthening of the rock strata surrounding permanent workings for their effective upkeeping,

- sealing off water inflows in the mine workings for reducing the cost of mine drainage.

The above could be also good reasons for planning post-grouting programs.

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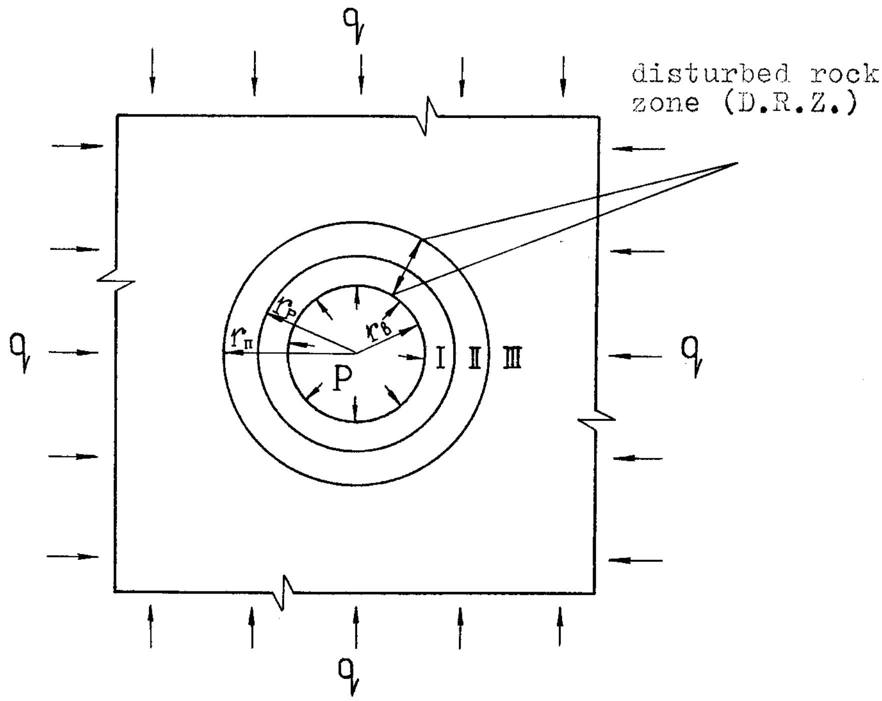

Fig. 1 Schemetic diagram of stress-strain condition of rock strata in the neighbourhood of underground excavation

I-zone of ruin failure

II-zone of post-failure condition

III-zone of pre-failure condition

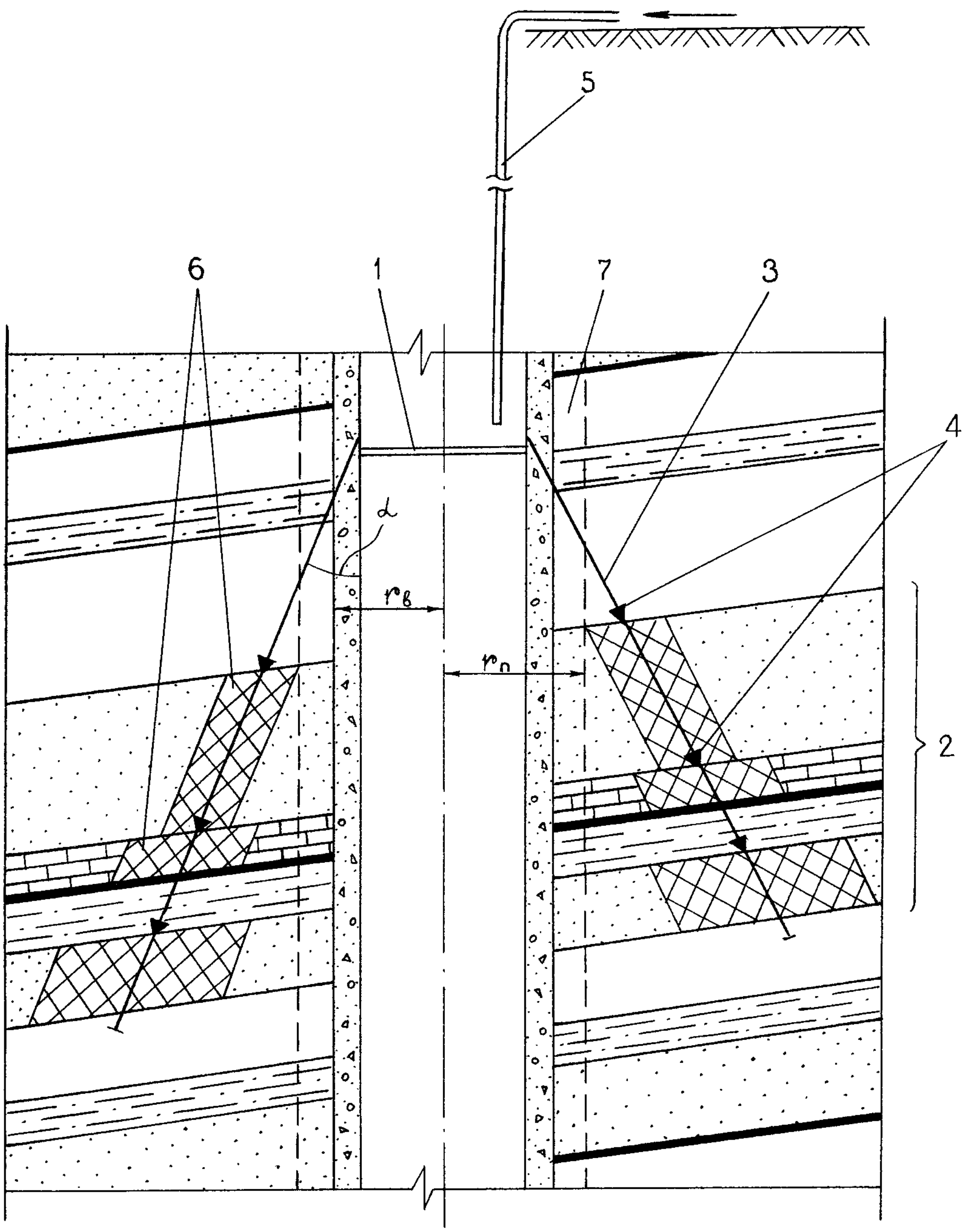

Fig. 2 Post-grouting procedure through directional extended injection boreholes

1-grouting stage level
2-separated watered zone
3-grout injection hole
4-points of packering
5-injection pipeline
6-grout covers, 7-zone of disturbed rock

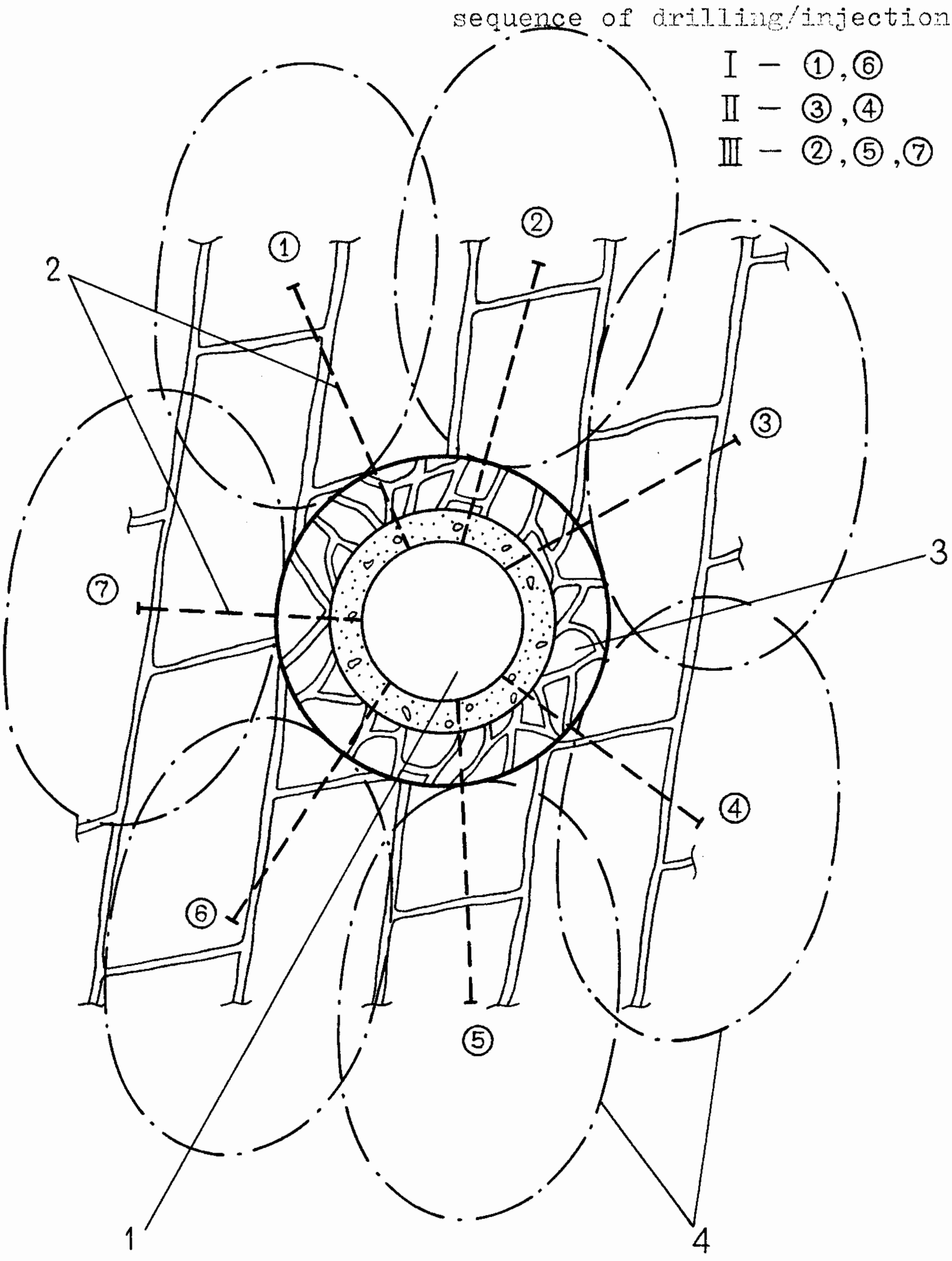

Fig. 3 Arrangement of grout covers in rock strata with intensive fracturing

1-mine shaft
2-grout injection holes
3-zone of disturbed rock
4-outline of grout covers

sequence of drilling/injection
I – ①, ③, ⑤, ⑦
II – ②, ④, ⑥, ⑧

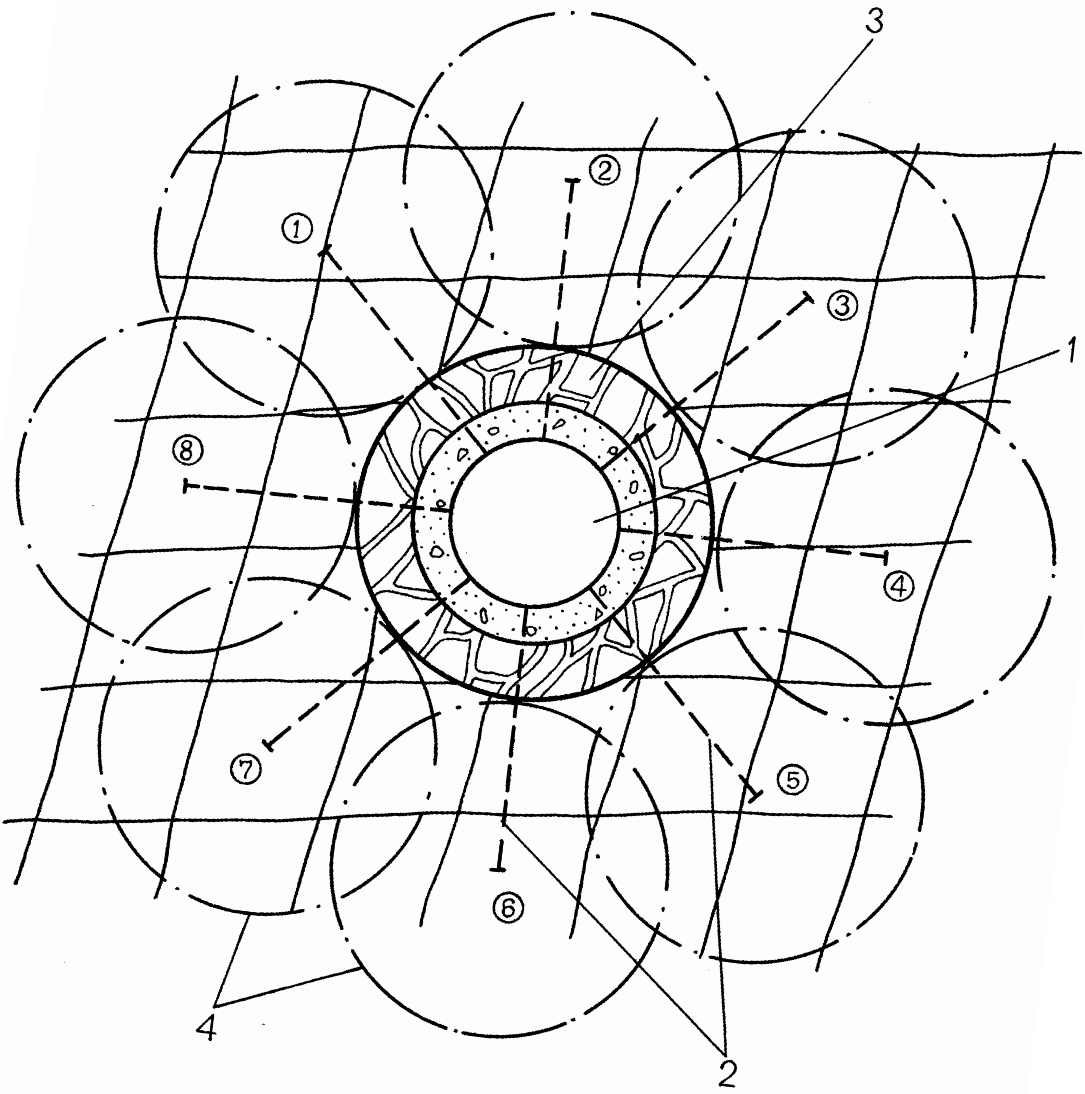

Fig. 4 Arrangement of grout covers in rock strata with uniform fracturing
1-mine shaft
2-grout injection holes
3-zone of disturbed rock
4-outline of grout covers