Technology of Hydraulic Barrier Erection by Injection Method

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ABSTRACT

A technology of erection of hydraulic barriers and soil-stabilizing structures formed in the course of injection of chemical and hardening materials is given. Mathematical relationships allowing the expected effect to be evaluated, are obtained, results of their practical application are stated.

INTRODUCTION

Hydraulic barriers, erected by injection method, are aimed at ground water regime conservation and prevention against pollution of aquifers, built with fractured rocks, cohesionless gravelly-pebble and sandy soils with seepage coefficient exceeding $2x10^{-5}$ m/s.

Injection type hydraulic barriers localize sources of ground water inflow or protect projects, i.e. pits, wells, mine shafts, open pits, tunnels and industrial sites against it.

Depending on specific conditions and economic considerations injection-type hydraulic barriers are erected at depths up to 100-150 m by method of injection of stabilizing fluids into seeping rocks. In some cases only selective stabilization of permeable strata will be quite sufficient.

The process of hydraulic barrier erection comprises drilling of row of holes followed by injection of chemically stabilizing mixtures which, being hardened in water-bearing rocks, form poorly permeable material. Silication and resin injection are the most widely used methods of stabilization.

Two-mixture silication is characterized by stage injection of sodium silicate with modulus 2,5 - 2,7, density 1,36 - 1,40 and calcium chloride with density 1,24 - 1,28. It is used in sandy, well-permeable soils. Gelation time depends on concentration and ratio of components in a mixture and can be adjusted within 0,5 - 16 hours.

When stabilizing loess soil by one-mixture silication its strength reaches 0,8 MPa. However, mechanical strength of soil, stabilized by silication, is reduced considerably when affected by water, enriched with carbonic acid. Hydraulic barriers of such type can be used as a temporary measure only.

The more reliable results are gained when using aqueous solutions of synthetic resins (f.e. carbamide - formaldehydes of types KΦ-MT, KΦ , KΦO et al.) for hydraulic barriers erection. Aqueous solutions of the acids are used for their hardening, oxalic acid being preferrable when carbonates are available in soils.

Gelation start depends on pH value and is usually present within 60 - 300 seconds. During this period water-saturated stabilized sands become highly watertight and result in reduction of the deepage coefficient 10^3 - 10^4 times, uniaxial compression strength increasing up to 3,0 - 7,0 MPa. When gradient values are up to 13000 material resists piping.

VIOGEM TECHNOLOGY

Technology of injection type stabilization without disturbance of rock structural bonds involves drilling holes and injection of stabilizing fluids into pore space through drilling tool - injector. Some injection schemes are known:

- through drilling tool;
- through standard injector;
- through double pipe.

These schemes have modifications of their own: drilling by runs from top downwards - advancing scheme; from bottom upwards - one and two-component 1,5 - charged scheme when components are mixed at the inlet of pressure lines and two - charged one when components are mixed at their outlet.

In Figure 1 a scheme of hydraulic barrier erection by method of runs, using advancing technology, is presented. Its disadvantage is low production rate and high deflection of holes from the preset direction. The more productive technology, corresponding to two-charged method, is used by us now. It makes it possible to increase production rate of stabilization operation, resulting in 3 to 4 m^3/hour of stabilized soil per team, keeping deflection of hole within standard values as they drill a hole first and then inject stabilizing fluid into it.

Work is done by drilling units of modernized series of URB -2A -2 type and special batching pumps of VIOGEM design. This equipment makes it possible to apply mixtures of short-duration hardening (less than 60 second), providing for uniaxial compression strength of stabilized sands up to 9,8 MPa, deformation modulus being 525MN/m^2.

Stabilization parameters, involved in this technology, are determined according to experimental relationship or results of test stabilization. Hole spacing (L) is determined by the formulae:

$$h=\sqrt[2]{3.35*R_3^2*\delta_3^2}-0.02*A*H,(m); \quad (1)$$

where: R_3- radius of stabilization effect, m;

δ_3- barrier thickness in a point of contact of resin-rock bodies formed in adjoining holes, m;
A - standard deviation of injection holes from preset direction in % by the depth , A = O,5%
H - hole depth, m;

Stabilization effect radius (R) is determined by the formulae:

$$R_3=0.8*K_3\sqrt[2]{\frac{K*\nu*P_{ckb}*t_h}{m*\nu_p*\varphi}},(m); \quad (2)$$

where K_3- stabilization factor, (K - 0,8 - 0,9):
K - seepage coefficient, m/s;
ν,ν_p- viscosity of water and mixture, m 2/s, respectively;
P_{ckb}- injection pressure, MPa;
t_h- duration of injection, s;
m- void filling factor, (M = 0,9);
φ- sand porosity, %;

Run length is taken to be approximately equal to 1,5 R_3, injection pressure (P_{ckb}) is determined by the relationship:

$$P_{ckb}\leq(0.77-1.14)*\gamma*H,(MPa); \quad (3)$$

where γ- gravitational force, N/m^3;

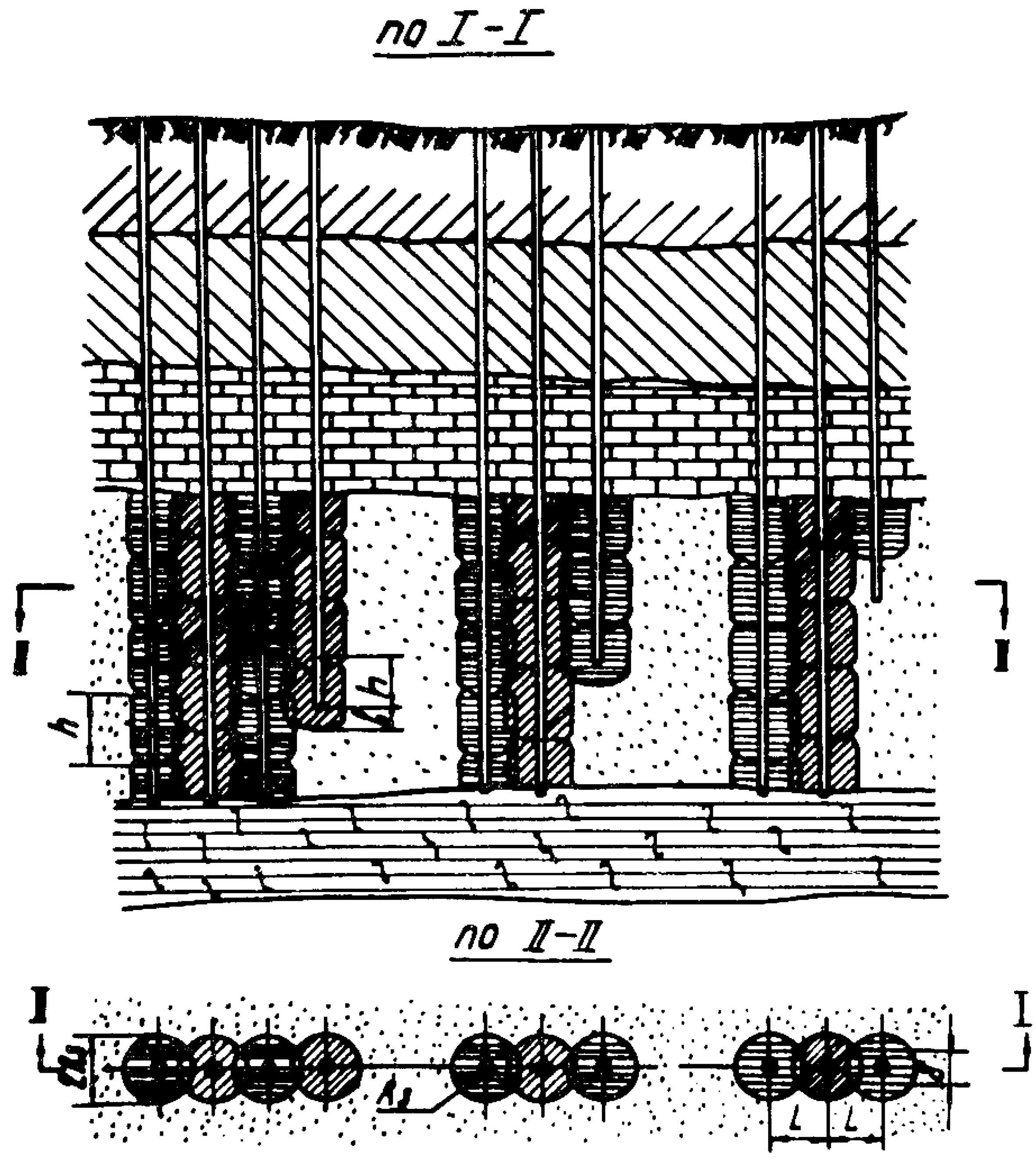
The volume of mixture to be injected into each hole (V_p) per run is determined by the formulae:

$$V_p=\frac{V_3*\varphi*m}{K_3^2},(m^3); \quad (4)$$

where V_3- volume of stabilized soil per run, m^3;

This technology of sand stabilization by injection method has been implemented during erection of experimental portions of hydraulic barrier provided in the walls of the Mikhailovsky and Stoilensky open pits of the KMA, vertical and inclined shaft sinking of Krivoy Rog mines, horizontal mine working drivage at Tavrichesky mining and beneficiation enterprise, sewage tunnel heading and stabilization of deeply-based foundation for paper-making machine at the Balakhninsky cellulose and paper production factory.

In fractured rocks with fracture opening up to $2x10^{-3}$ m this technology was used for erection of hydraulic barrier to 100 m depth around "Skipovaya" mine shaft of the Bashkir copper and sulphur Mine Integrated Works.



Explanation: 1 - hole spacing, R_3 - radius of stabilization effect, h - injection run length.

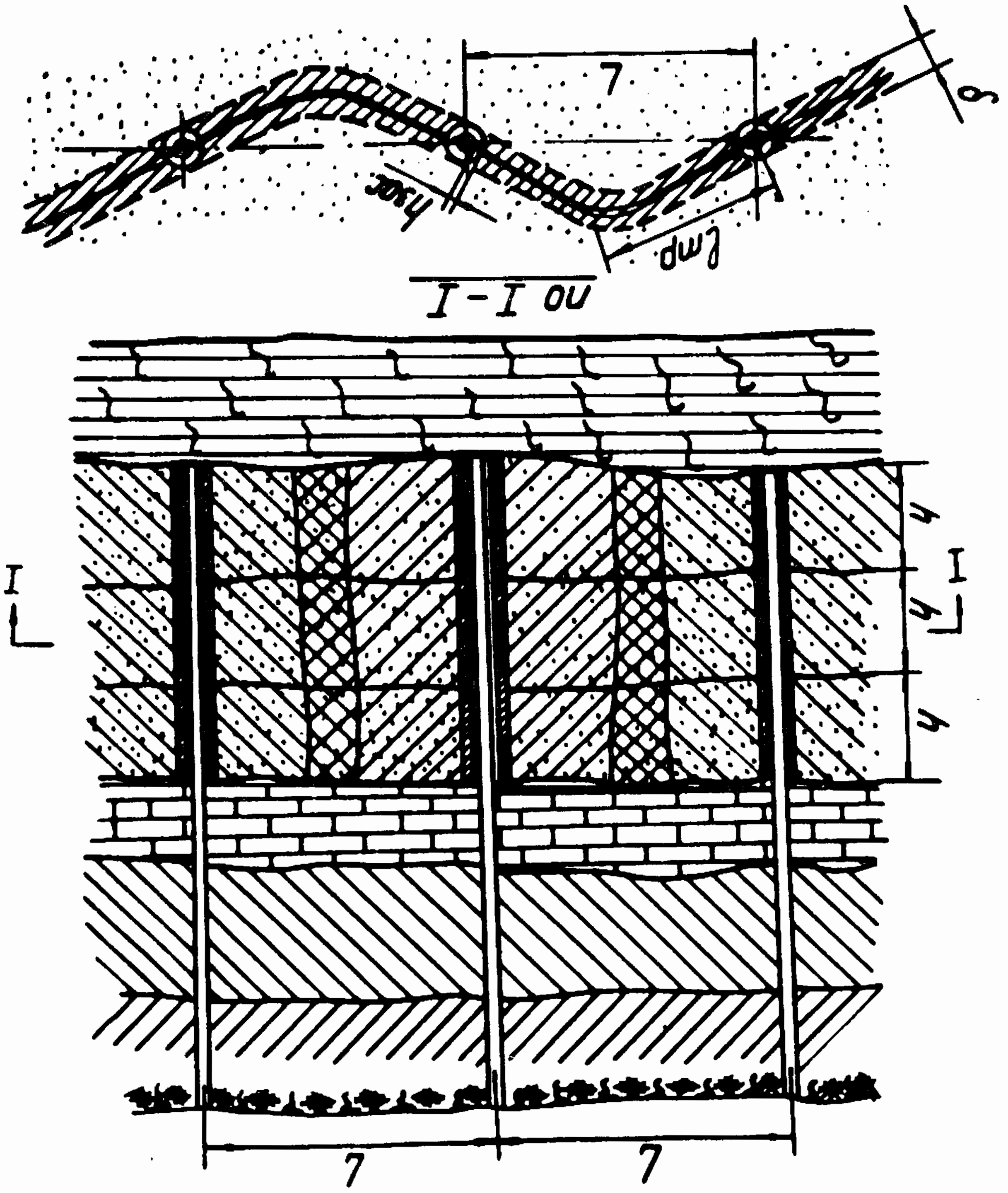
Figure 1: Hydraulic barrier erection according to advance injection scheme.

As hydraulic barrier cost involves expenses for hole drilling and equipment installed in them, for purchasing, preparation and injection of mixtures then costs should be cut down due to hole number reduction and thinning of the barrier, i.e. reduction of volume of fluid injected. This aim is obtained by application of method of injection out of directional hydraulic fractures.

Technical decisions based on this method are original ones and are elaborated on the level of invention. This method makes it possible to pump mixture from the holes in the preset direction, forming vertical or horizontal walls consisting of stabilized rocks and hardened stabilizing composition, synthetic resin polymer, in particular. Equipment, used for this method realization, is simple and reliable in operation. Holes are drilled with standard drilling units and tools. Stabilizing fluid is injected also through drilling tool. However, to provide directional hydraulic fracturing concentrations of stresses are induced by means of special tool applied on any portion of a hole. Injection is carried out with pumps of injection or flushing type of increased capacity. Scheme of hydraulic barrier erection, using directional hydraulic fracturing, is given in Figure 2.

Application of the said method makes it possible to form hydraulic barriers with the following thickness: in sands - 0.2 - 0,3 m, in loam soil - up to 0,15 m, in clays - 0,04 m, i.e. beyond the limits of reaching of injection methods used in common practice. Productivity of labour when injection work is being carried out is two times increased; consumption of stabilizing fluid and number of wells are reduced.

Injection method used for hydraulic barrier erection even to shallow depths can advantaneously compete with a trench wall method, as experince proved to be, if only seepage barrier is required.



Explanation: L - hole spacing, δ - hydraulic barrier thickness, l_{tp} - hydraulic fracture length, h - injection run height.

Figure 2: Scheme of hydraulic barrier erection using directional hydraulic fracturing.