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Algorithms of Optimum Slurry Selection for Soil and Rock Sealing Operations

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Abstract

Technical problems, usually caused by complex geological and hydrogeological conditions, are often encountered in mining, drilling and geoengineering operations, as well as in hydrotechnical and underground construction.

Natural hazards in the above engineering operations are frequently liquidated by reinforcement and sealing of the ground with the use of injection methods with pre-selected sealing slurries.

The authors present methods for slurry technological parameters normalization, depending on the scope and target of sealing operations, and algorithm of slurry selection of soil and rock sealing.

Key words: *algorithm of slurry, selection of soil, rock sealing, geological and hydrogeological conditions*

Introduction

A number of technical problems appear in the course of drilling, in hydrotechnical construction and in various geoengineering applications. They are usually caused by complex geological and hydrogeological conditions; frequently they are due to technological mistakes at the stage of realization [3,4].

The natural hazards accompanying engineering projects necessitate activities, the aims of which are the following:

- elimination or minimization of physical discontinuities of geological strata;
- improvement of physical and mechanical properties of the ground or rock mass, especially their compactness, strength and permeability;
- liquidation or reduction of ground and formation waters influx to the workings;
- closing or separation of oil and gas horizons as well as the onlying gangue, to stop hydrocarbon migration between them.
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The basic works thanks to which the above objectives can be attained lie in the isolation, stabilization, reinforcement and sealing of the ground or rock mass around the realized workings or engineering objects.

The well selected engineering operations are a guarantee of properly performed prevention measures. Owing to its high efficiency, borehole injection with properly selected sealing materials is the most commonly used. The popularity of soil and rock mass reinforcement and sealing method results from the accessibility of a vast range of types of sealing materials.

Both organic and inorganic, Polish and foreign hydraulic cements are now available on the drilling market. They broadly vary in their physicochemical properties and prices. There is no universal cement which could be used for making a sealing slurry that would meet all technical requirements encountered when isolating, stabilizing, reinforcing and sealing soil and rock mass. This is greatly due to the specific objectives and scopes of undertaken operations.

Methods of sealing slurry technological parameters normalization

The efficiency of sealing slurry application in engineering works depends on the following factors:

- - target;
- - structure of the ground or rocks, their physical and chemical properties;
- - kind and cost of the applied technique and technology.
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On the basis of the analysis of these factors, admissible ranges of physical properties, rheological and technological parameters of liquid and solidified sealing slurries can be determined. Then optimum decision has to be chosen from the following criterial function:

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$$K = \sum_{i=1}^{N} w_i f_i \rightarrow \max \quad (1)$$

Individual technological parameters of fresh and set sealing slurries vary in their values. This diversity results from proportions of the components and their chemical composition of the slurries.

Owing to considerable differences in absolute values, ranges of variability and different physical values of individual parameters (e.g., density of slurry $\rho = 1720\ kg/m^3$, apparent viscosity $\eta_a = 0{,}14$ Pas) should be unified. This should enable a comparison of values and scales of individual parameters and their application to the assumed criterial function (1).

To do this, the values of specific variables F_i are proposed to be normalized to f_i values from [0,1]. Therefore, an admissible variability range is established for each physical, rheological or technological parameters:

$$F_i \in [F_{MIN}, F_{MAX}] \quad (2)$$

The admissible range of variability of F_i values results from technical and technological possibilities of making and using sealing slurries. Normalized f_i value of F_i variable should be calculated from the respective formulae, depending on the influence of the analyzed variable on the criterial function values. When the influence of a given variable on the criterial function value is proportionate, then the normalized f_i value of F_i variable should be taken from the formula:

$$f_i \in \frac{F_i - F_{MIN}}{F_{MAX} - F_{MIN}} \quad (3)$$

Otherwise, the below dependence holds true:

$$f_i \in \frac{F_{MAX} - F_i}{F_{MAX} - F_{MIN}} \quad (4)$$

Determining significance weights of individual slurry properties is the most crucial task realized in the process of sealing slurry optimization. Its value depends on the target and results of performed engineering works. Specific physical properties and technological parameters vary in significance, therefore the following groups of sealing slurries can be distinguished: [1,2]

I grup – very significant properties;

II grup – significant properties;

III grup – properties of little significance;

Within each group, an increasing significance hierarchy of the parameters can be established.

An exemplary division of technological parameters of sealing slurries into significance groups and their hierarchy within a given group, for various applications, are given in table 1. [1,2]

Table 1. Hierarchization of technological parameters of sealing slurries for various applications

Significa-nce group	***Sealing of annular space***		***Sealing of the rock mass of a ground medium***	
I	*1*	*density*	*1*	*compression strength of set sealing slurry*
	1	*filtration*	*1*	*bending strength of set sealing slu*
	2	*sedimentation*	*2*	*cost of 1 m sealing slurry*
	3	*beginning of sealing slurry setting*		
	3	*end of sealing slurry setting*		
	4	*cost of 1 m sealing slurry*		
II	*1*	*assumed viscosity*	*1*	*assumed viscosity*
	1	*plastic viscosity*	*1*	*plastic viscosity*
	1	*apparent viscosity*	*1*	*apparent viscosity*
	1	*yield point*	*1*	*yield point*
	1	*structural strength*	*1*	*structural strength*
	2	*unit pressure losses*	*2*	*unit pressure losses*
	3	*fluidity*	*3*	*beginning of sealing slurry setting*
			3	*end of sealing slurry setting*
III	*1*	*compression strength of set sealing slurry*	*1*	*density*
	1	*bending strength of set sealing slurry*	*1*	*filtration*
	2	*pH of filtrate*	*2*	*sedimentation,*
			3	*fluidity*
			4	*pH of filtrate*

Pre-selection of weights should be based on the assumption of a proportionate influence of the hierarchy in individual groups on the target function (1), and assuming that the least weight value of a group of more significance is k-times (e.g. twice) bigger than the highest value in the group of less significance.

For such assumptions, local weights are calculated for each parameters inside the specific groups, using the following formulae;

- for I group:

$$W_{GI,j} = \frac{h_{GI,max} - h_{GI,j} + 1}{\sum_{j=1}^{N_{GI}} \left(h_{GI,max} - h_{GI,j} + 1\right)} \tag{5a}$$

- for II group:

$$W_{GII,j} = \frac{h_{GII,max} - h_{GII,j} + 1}{\sum_{j=1}^{N_{GII}} \left(h_{GII,max} - h_{GII,j} + 1\right)} \tag{5b}$$

- for III group:

$$W_{GIII,j} = \frac{h_{GIII,max} - h_{GIII,j} + 1}{\sum_{j=1}^{N_{GIII}} \left(h_{GIII,max} - h_{GIII,j} + 1\right)} \tag{5c}$$

Then, global weights for each slurry parameter in the specific groups are calculated.

- for I group:

$$w_{GI,j} = W_{GI,j} \cdot \frac{k^2 \cdot \frac{W_{GIII,1}}{W_{GII,N_{GII}}} \cdot \frac{W_{GII,1}}{W_{GI,N_{GI}}}}{1 + k \cdot \frac{W_{GIII,1}}{W_{GII,N_{GII}}} + k^2 \cdot \frac{W_{GIII,1}}{W_{GII,N_{GII}}} \cdot \frac{W_{GII,1}}{W_{GI,N_{GI}}}} \tag{6a}$$

- for II group:

$$w_{GII,j} = W_{GII,j} \cdot \frac{k \cdot \frac{W_{GIII,1}}{W_{GII,N_{GII}}}}{1 + k \cdot \frac{W_{GIII,1}}{W_{GII,N_{GII}}} + k^2 \cdot \frac{W_{GIII,1}}{W_{GII,N_{GII}}} \cdot \frac{W_{GII,1}}{W_{GI,N_{GI}}}} \tag{6b}$$

- for III group:

$$w_{GIII,j} = W_{GIII,j} \cdot \frac{1}{1 + k \cdot \frac{W_{GIII,1}}{W_{GII,N_{GII}}} + k^2 \cdot \frac{W_{GIII,1}}{W_{GII,N_{GII}}} \cdot \frac{W_{GII,1}}{W_{GI,N_{GI}}}} \tag{6c}$$

Global weight w_i values in the whole slurry population is determined from the following formulae:

- for $0<i\leq N_{GI}$ $\quad w_i = w_{GI,j}$, where $j=i$ (7a)

- for $N_{GI} < i \leq N_{GI} + N_{GII}$ $\quad w_i = w_{GII,j}$, where $j=i-N_{GI}$ (7b)

- for $N_{GI} + N_{GII} < i \leq N_{GI} + N_{GII} + N_{GIII}$ $\quad w_i = w_{GII,j}$, where $j=i-N_{GI} - N_{GII}$ (7c)

Denotations:
f_i – normalized value of i-th parameter,
F_i – value of i-tej parameter,
F_{MIN} – minimum value of F_i variable,
F_{MAX} – maximum of value of F_i variable.
$h_{GI,max}$ – maximum value in I group hierarchy,
$h_{GII,max}$ – maximum value in II group hierarchy,
$h_{GIII,max}$ – maximum value in III group hierarchy,
$h_{GI,j}$ – value of j-th parameter in I group,
$h_{GII,j}$ – value of j-th parameter in II group,
$h_{GIII,j}$ – value of j-th parameter in III group,
i – sealing slurry properties index for the whole slurry population,
j – sealing slurry properties index in significance groups,
k – multiplication of significance weights between the highest weight in a group of less significance and the smallest weight in the group of the highest significance,
K – criterial function,
n – number of sealing slurries meeting the target function,
N – number of factors (properties) of the analyzed sealing slurries,
N_{GI} – population of I group,
N_{GII} – population II group,
N_{GIII} – population of III group,
$W_{GI,j}$ – local weight of j-th property in I group,
$W_{GII,j}$ – local weight of j-th property in II group,
$W_{GIII,j}$ – local weight of j-th property in III group,
$w_{GI,j}$ – global weight of j-th property in I group,
$w_{GII,j}$ – global weight of j-th property in II group,
$w_{GIII,j}$ – global weight of j-th property in III group,
$W_{GI,1}$ – local weight of the most significant property in I group,
$W_{GII,1}$ – local weight of the most significant property in II group,
$W_{GIII,1}$ – local weight of the most significant property in III group,
$W_{GI,NGI}$ – local weight of the least significant property in I group,
$W_{GII,NGI}$ – local weight of the least significant property in II group,
$W_{GIII,NGI}$ – local weight of the least significant property in III group,
w_i – weight of influence of i-th property on the quality function, determined for the whole population of sealing slurries.

Resume

This method requires fulfilling the following requirements:

1. Derivation of slurry recipe data and technological parameters established on the basis of laboratory experiments.
2. Definition of the target.
3. Definition of significance weights for individual technological slurry parameters (formulae 7a,7b and 7c).
4. Definition of limitations for individual technological slurry parameters.
5. Establishing a set of „n" recipes for sealing slurries applicable in complex technological conditions.
6. Normalization of specific technological slurry parameters (formulae 3 or 4).
7. Calculation of criterial value K (formula 1).

Optimum sealing slurry recipe is considered to have a maximum value of a target function.

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