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Assessment of Deformations of Earth`s Surface at Mine Construction on Sub-Soils

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Abstract

The paper provides technical and technological solutions aimed at construction and support erection for up to 50 m deep underground facilities of a relatively moderate extend up to 100 m in unstable mantle rocks, which are carried out by small splitting according to the combined pattern without any specific methods. Thus, reduction of cost and construction period is achievable, which is of a significant importance for resource saving.

The authors describe results of studies focused on development of methods to provide support of underground facilities with mass concrete under conditions of semi-stable rocks and application of the combined pattern. Reduction of the splitting value to 0.3 m results in decrease of plastic deformation area by 1.7 times and maximum displacements of adjacent strata contour with 10–15 kPa adhesion factor by 1.5 times.

When an optimum volume of modifying agents are added to the composition, concrete strength is improved by 1.7 times after 12 hour curing and by a factor of 7 after 24 hour curing in comparison with that without any additives. The finite element theory was applied at simulating the stress-strain behavior of the non-supported bottom-hole area of rock solid mass and hardening concrete of the monolithic lining erected after wall advance. In such a manner, distribution of maximum strains in the support has been revealed with due regard to concrete hardening.

The authors provide a regression model for calculation of an optimal value for splitting and selection of structure and support parameters. Areas of maximum displacements in the solid mass and their influence on the Earth surface deformation have been determined.

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Keywords: advance; support; concrete strength; stresses; simulation; experiment plan; multiple regression.

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1. Introduction

Underground urbanization is actively developing in the world and foreign experience shows that to ensure a sustain-able balance and a comfortable stay in the city share of underground facilities of the total area of commissioned facilities should be 20-25% [20].

Despite the complexity and volume of work, as well as the high cost, the increase in the volume of construction of underground facilities and tunnels is a general trend for all developed countries of the world, since the deficit in urban areas requires the development of underground space [21].

Development of underground space in large cities demands growth of volumes construction developments in massifs of alluvial soils which it is frequently characterised by very difficult conditions of passage. Therefore in some cases even expensive design technological solutions of carrying out and bracing do not exclude serious complications to what experience of building of tunnels of different function in Moscow, Ekaterinburg, Perm, Ufa and slopes of mines in the Rostov area testifies.

Small durability of alluvial rocks and accordingly the big displacement without failure сплошности a massif cause application of special actions for hardening of a containing massif, and also solid bearing weight concrete and the reinforced concrete constructions which are carried up after construction with a temporary support. In this case specific expenses for building of underground constructions of small extent to 100 m essentially increase. Thus, perfection of a construction method of underground constructions in soil massifs with low physicomechanical properties of soils gets a special urgency.

To lower displacement of soils and accordingly probability of a breaking-down of a loose massif at building of constructions in priming coats it is possible reduction of size of moving of working face to 0,3 - 0,7 m that will allow to minimise plastic deformations of a contour of a development and to exclude breaking-downs of a loose massif of cohesive soils. Mounting quick-situ concrete immediately behind the outcrop of rocks will significantly reduce the cost, duration and complexity of the work and materials consumption.

2. The effect of the size of moving of working face on the deformation of the face of underground structures

Evaluation of stress-strain state of the array of soil by reducing the length moving of working face was made by three-dimensional finite element modeling generate a circular shape [1, 2]. For this purpose, on models with identical characteristics of a massif of soils, an underground construction and a support, character of distribution of sizes of stresses and deformations on a longitudinal axis of a development is investigated.

Analyzing a stress distribution in an untouched massif on distance from working face (fig. 1), it is possible to notice of 0,6 m, that number of knots with the stresses close to limiting in models with size of moving of working face of 1,0 m (fig. 1b), much more, than in a model with size of moving of working face 0,3 m (fig. 1a).

The maximum sizes of stresses are observed in the central working area of working face. It testifies to a stress concentration on working face from weight of the dome of natural equilibrium formed over a loose working area. Nodes with maximum values of stresses are absent.

On the plane of working face (fig. 2) concentration of knots with limiting stresses is maximum in both models, however at size of moving of working face of 1,0 their m is much more. Also it is possible to notice, that knots with limiting stresses are observed only in a construction, not leaving for its contour. That is ledge on a development contour is less subject to deformations and can be developed directly ahead of concrete packing.

In a loose working area to equal size of a pull, knots with limiting stresses are observed in a massif only in the second model, and all of them settle down on a massif contour. It testifies that an exposure on depth of 1 m causes excessive shift deformations.

Simulation of the stress-strain state of the soil mass and concrete lining in the bottom hole of the production found that a working area of distribution of plastic deformations in a development with size of moving of working face 1 m in 1,7 times more, than at moving of working face of 0,3 m and exceed admissible, that provokes a breaking-down. Reduction of size of a pull reduces plastic deformations of a loose part of a development and working face providing stability of a pedigree contour. Reduction of amounts of works in a cycle reduces time spacing between an exposure of a pedigree contour and placing concrete.

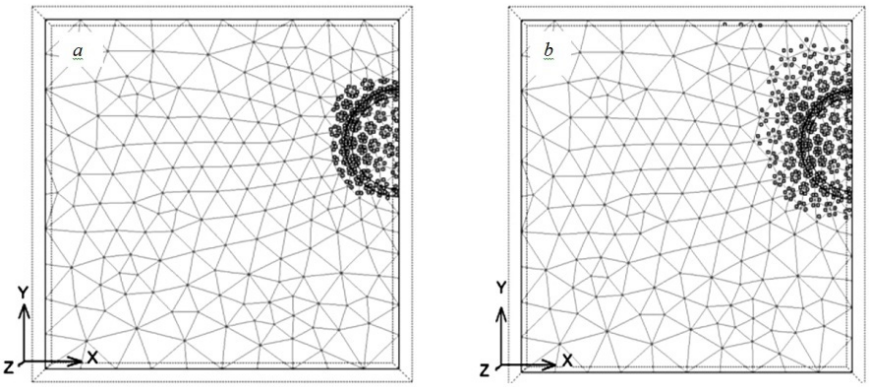

Fig. 1. Concentration of stresses in a soil massif on distance of 0,6 m from a working face plane: a - size of moving of working face of 0,3 m; b - size of moving of working face 1,0 m

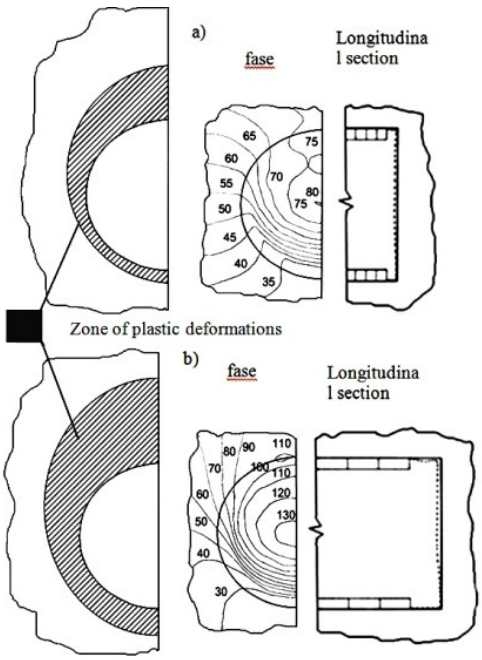

Fig. 2. Development of zones of plastic deformations

In this case, monolithic concrete lining being built immediately after face advance, through a short time interval should perceive the loadings transmitted by the array of rocks. That is application of rapid-hardening and high-strength structures is necessary.

3. Study of mechanical properties of modified concrete

With regard to the construction workings short site raises the question of the speed of passage, since the decrease in proportion to the depth of site and reduce the rate of penetration. In this case, to ensure the passage of standard

speeds necessary to shorten the cycle time 9 - 12 hours thus 9 hours through the concrete should not be pressed into the face of underground structures under its own weight and the pressure deformable soil mass.

Experience of application in building of concrete with high early durability shows, that there is a set of ways and control facilities a kinetics of structurization and of a set of durability concrete (magnetic and electric activation of water, mechanical activation of cement, warming up of the laid concrete mix, application of modifying additives) [3-7].

However in underground excavations early strength concretes have not found applications, in view of specific technology of erection of supports in developments [8, 9] and impossibility of realisation of the majority of ways of management of a kinetics of hydration of cement. Therefore, the use of modifying additives of multifunctional action will be most effective to increase the early strength of the concrete and therefore the bearing capacity of the lining.

For reception of concrete with high early durability variety of the structures modified by complex additives is investigated. On the basis of trial of samples of the concrete prepared on various compoundings, the most effective structures are defined and dependences of growth of a compression strength in time are established.

Due to the nature of formwork designs, limited scope of work, lack of opportunity to seal vibrators and duration of the process of laying the mixture especially in the upper part of the vault, you must preserve the mobility of staff for 30 - 40 minutes. Since the mine construction is mainly used cast concrete mixtures with slump to 17 cm, with conventional concretes above basic value range does not. In the application of fast setting concrete intensification of structure formation in the early stages of hardening is accompanied by a decrease in mobility and an increase in mixing time during installation and durability. That is, except for the growth of the strength of an evaluation of the time of mixtures of mobility. Research efforts revealed that the composition had the best performance, D-5 modifier in an amount of 4% by weight of binder.

Since the underground construction work processes are performed sequentially, the period of preparation of a concrete mixture before entry into the lining operation may be different. Therefore for amenity of designing of parametres of bracing, dependence of a set of durability of concrete of various structures on time of a set of durability is required to be approximated. Since the strength characteristics of concrete is mainly determined by the strength of the cement stone, then the selection of the optimal composition of concrete binder ratio and modifier did not change. Required mobility was achieved by calculating the water-cement ratio.

To obtain reliable results of studies of concrete samples, each part in all 12 time intervals hardening was prepared and was tested three times in accordance with the requirements of GOST [10-13].

Analyzing results of researches of the modified concrete, it is possible to notice, that logarithmic dependence well describes a kinetics of a set of durability of the modified structure only after the first days of a set of durability. Since the most important period is an interval of 6 to 18 hours, the strength development of concretes expedient divided into two graphs from mixing up to 24 hours and from 24 to 72 hours.

Results of approximation of laboratory researches of the modified concrete are resulted in table 1. It will allow, depending on the accepted parametres of carrying out of a development, on regression to the equations 1-6 to count durability of concrete during time of a set of durability necessary for designing.

Table 1. Results of approximation of dependence of a set of durability on compression of the modified concrete from time of a set of durability.

Structure and quantity of additives	The regress equations, for an interval of a set of durability:	
	till 24 hours	from 24 till 72 hours
D-5 (2%)	0,016t2 – 0,086t – 0,01 (1)	6.247 ln(t) – 12.62 (2)
D-5 (2%) and sodium silicate (1%)	0,020t2 – 0,106t + 0,055 (3)	10.63 ln(t) – 24.70 (4)
D-5 (4%)	0,025t2 – 0,107t – 0,082 (5)	15.66 ln(t) – 38.15 (6)

As process of definition of the module of elasticity of concrete is rather labour-consuming, and for modelling its values on twelve intervals of a set of durability, various mixes and with possible changes kinetics a durability set are required, has been decided to establish dependence of the module of elasticity of optimum mixes on their strength on compression.

Manufacturing of samples from a concrete mix was made in accordance with GOST 10180-78. Longitudinal deformations were defined optical projective microscope KM-8, and cross-section by the indicators of hour type providing measurement of deformations with accuracy of 1·10–6 м. Base of measurement of longitudinal deformations has been accepted 200 mm.

The analysis of results of tests of 106 samples of cubes and 38 prisms, has allowed to define dependence of the module of elasticity of concrete E1 on durability of samples on compression σ. As the area of researches is characterised by the big range of change of durability (0,2 - 40 MPa), to describe one equation of regress received results with high level of reliability is impossible. Therefore all range of researches is divided into three intervals on durability of concrete: 0,5-2,0 MPa; 2,0-15,0 MPa and 15,0-40,0 MPa.

The first interval is defined by area of the earliest terms a set of durability at durability on compression to 2,0 MPa. Results of tests are approximated by sedate dependence

$$E_1 = 525\sigma^{1,66} \quad (1)$$

the second interval is characterised by linear dependence

$$E_1 = 1100\sigma - 342 \quad (2)$$

and the third is described by the equation

$$E_1 = 14806\ln(\sigma) - 21542 \quad (3)$$

The received results allow at modelling of the VAT by a method of final elements, to use as the operated factor durability of concrete on compression in calculations of the maximum stresses in a support instead of labour-consuming tests by definition of the module of elasticity.

4. Research of stresses and deformations of a soil massif and a concrete support

On the basis of the received parametres kinetics a set of durability concrete of in three-dimensional statement of a problem with use FEM and optimum planning of experiment [14-15], computer modelling of system "support - soils", taking into account a set of durability is executed by concrete of each of moving of working face.

At modelling distribution of stresses in a concrete support strengthened in time and a soil massif, and also movings of a contour of a construction and an earth surface is investigated.

For calculations the spatial model of an isotropic massif of a soil, with the construction of a circular outline located in it the fixed monolithic concrete support is accepted. The constructions support is loaded by a rock pressure, axis Z coincides with a longitudinal axis of a construction, and an axis X and Y according to horizontal and vertical axes of cross-section section, that is the symmetric problem (fig. 3) is considered.

The estimation of the is intense-deformed condition of a soil massif is executed with application of model of the linearly-deformed environment based on the theory of elasticity, together with the model of destruction based on the theory of durability Kulon-Mor which is in overwhelming majority used at building of developments in alluvial soils [16-17].

As optimisation parametre the maximum stresses and displacement of a contour of a constructions which concentrate on some removal from working face are accepted and depend on variety of factors [18]: a rock pressure, the size of a constructions; parametres of a support, characteristics of concrete and soils of a containing massif. On a basis before the executed researches the most significant factors, to the greatest degree, influencing stresses in a support are revealed: size of moving of working face - l; size of pressure upon a support - P; a thickness of a support - h; ground bond - Cs; increasing in a current of time durability of concrete - Rc.

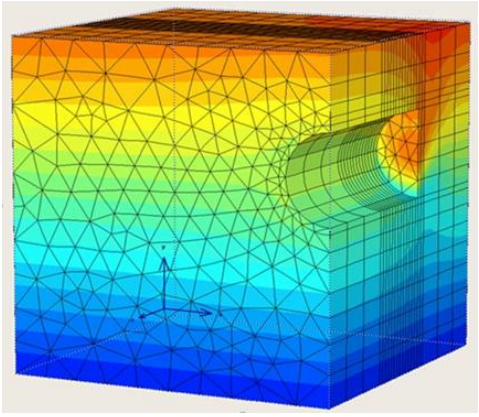

Fig. 3. Model of a massif with a construction

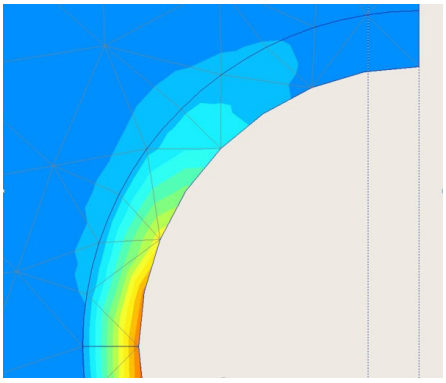

Fig. 4. Distribution of the maximum stresses in a wall on an internal contour of a support at age of concrete of 18 hours

Realisation of the plan of experiment has allowed: to reveal zones and sizes of the maximum stresses in a support in process of removal from working face which are localised in a wall on an internal contour of a support (fig. 4) and reach a maximum in the third fixed of moving of working face.

This results from the fact that in the third of moving of working face the modified concrete at the age of 18 hours has passed from a plastic condition in solid, and perceives loadings from a rock pressure. Thus, the maximum stresses in a support are shown on distance 0,9 - 2,8 m from working face, depending on constructions parametres.

Character of change of stresses in a support typing durability in process of advancement from working face is presented on a drawing of change of stresses on a longitudinal axis of the construction, received by results of computer modelling (fig. 5)

The maximum tensile stresses are discovered in a constructions crest, also on an internal contour of a support, however their value there is less than strength of concrete at tension at corresponding age. The overall picture of distribution of stresses in a support, corresponds described in a source [18] that allows to consider the obtained data authentic.

The major parametre defining rates of building of a constructions is time of a cycle of passage and the fastening which duration depends on speed of a set a support of durability and is defined by the moment when durability of concrete starts to exceed stresses operating in it (at least on 10 %).

The profile is applied to definition of duration of a cycle (fig. 6) displaying change of durability of concrete and change of stresses in a support in time is constructed, at use of the modified concrete with the additive of 4 % D-5 from cement mass.

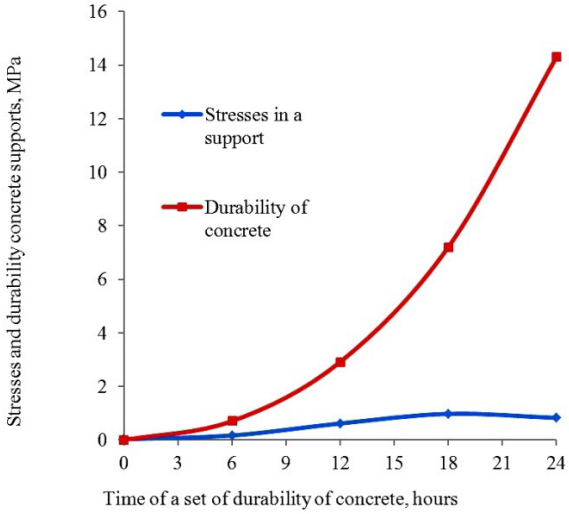

Fig. 5. Distribution of stresses in a support in process of removal from working face and a set of durability concrete (In a wall on an internal contour)

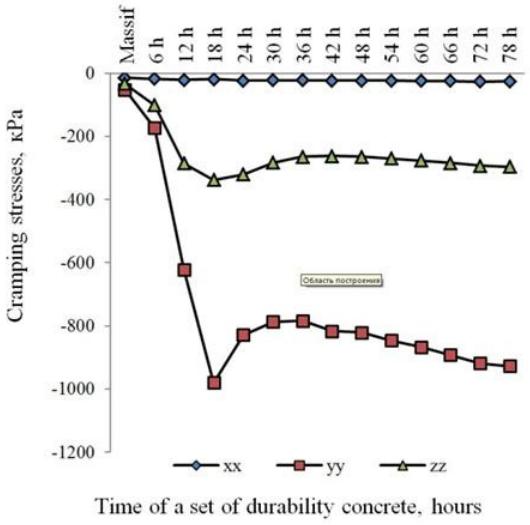

Fig. 6. - Change of durability of concrete and stresses in a support in time

The analysis of the results resulted in drawing shows, that at use of the modified concrete with high characteristics of durability, its durability starts to exceed operating stresses in 6 hours after manufacturing, that in the considerable image affects duration of a cycle and accordingly on buildings terms.

Processing of the received results of modelling has allowed to receive the equations of plural regress for calculation of the maximum stresses operating in a support in process of advancement from working face, for various age of concrete.

The made statistical analysis has shown high correlation of the equation of plural regress: for age of concrete of 6 hours - polynom function, the equation for age of concrete of 9 hours is similarly deduced; for age of concrete from 12 o'clock till 3 days - function exhibitors. By means of the program «Statistica» factors of the equations are defined. Thus, following equations of plural regress are received:

for 6 hours

$$\sigma = -5,97 - 0,39l + 0,31l^2 + 3,17P - 2,71P^2 + 26,5h - 32,68h^2 - \\ -101,96C_s + 3094,12C_s^2 + 22,92R_c - 106,41R_c^2 \quad (4)$$

for 9 hours

$$\sigma = -22,07 + 4,91l - 4,29l^2 + 11,4P - 8,7P^2 + 102,3h - 129,08h^2 - \\ -788,86C_s + 25829,12C_s^2 + 7,55R_c - 2,82R_c^2 \quad (5)$$

for 18 hours

$$\sigma = -6,41 + exp(1,36 + 0,27l + 1,69P + 0,37h - 10,61C_s + 0,03R_c) \quad (6)$$

Also the equation is deduced regression, allowing to define the maximum size of moving of working face not causing a roof fall depending on durability of concrete at compression corresponding to age at which the extraction of the following moving of working face and size of pressure upon a support is made:

$$L = 0,634 + 0,368R_{c(xhours)} - 1,347P \quad (7)$$

where Rc(x hours) – durability of concrete, MPa, aged at which bearing capacity of a support not less than in one and a half time exceeds stresses operating in it.

At modelling the estimation of deformations of a surface is made. It is as a result established, that the maximum displacement are observed in an untouched massif of a ground on distance 0,8-1,3 m from development working face.

In drawing 7 settlement displacement of a surface on a longitudinal axis of a development for models with the most adverse combinations of operated factors are resulted.

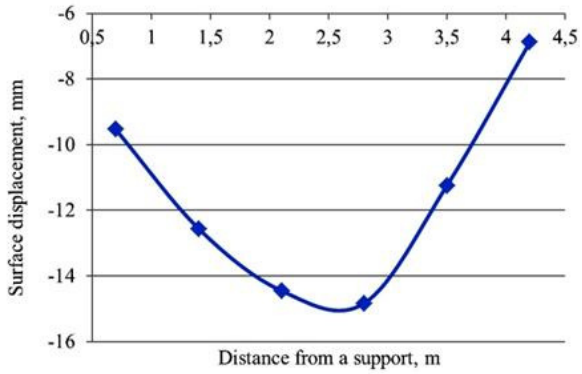

Fig. 7. Surface displacement over a construction at: to size of moving of working face - 0,7 m; to depth of location - 50 m; factor of bond of a ground - 13,8 кPa

Statistical processing of results of modelling of deformation of a surface has allowed to establish the most signif (8) for definition of the greatest possible settling of a ground over constructions.

$$\Delta = -1170.79 + exp(7,08 - 0,01l - 0,02P + 0,002h + 0,11C_S - 0,02R_C) \quad (8)$$

The size of reliability of approximation of the equation of regress makes R2=0,695, and a standard error 3,11.

On the basis of researches the algorithm and a technique of designing of parametres of the organisation of operations is developed. The technology of building of constructions by short of moving of working face with fastening by especially quickly hardening concrete is offered. In offered technology for prevention of losses of a concrete mix the sealing pneumoelement representing a part of a toroid with cross-section section in the form of a dumbbell which is established between a timbering and massif walls is used. The construction of a collapsible timbering which is protected by the patent for useful model [19] is developed.

5. 5. Conclusion

The executed researches have allowed to establish:

- Dependence of change of mechanical characteristics of the modified structures on time of a set of durability of concrete, a kind and quantity of additives;
- Influence of size of moving of working face, mechanical characteristics of a ground and concrete on formation of a zone of plastic deformations, displacement and stability of a loose part of a massif;
- Correlation dependences of the maximum stresses in a support and surface displacement over a development from: thickness of a support; rock pressure sizes on it; size of moving of working face; factor of bond of a ground and the module of elasticity of concrete of the support, allowing to estimate an intense condition of a support with mechanical characteristics of the modified concrete changing in time and to define surface deformations.

Thus, creation is theoretically proved:

- Techniques of designing of parametres of carrying out and fastening of underground constructions in unstable rocks;
- Techniques of the control of changing durability of the hardening concrete support, allowing to define is minimum possible duration of a cycle.

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