General Conditions for Estimation of Stress-Strain State of the Rock Massif for Objects of Civilian Potection

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Abstract

New calls for global security today, since operations the era of uncontested military superiority of western forces is fading and western response can't simply be to avoid operating in these environments but we should start to think about essential to protection of our potential in industry, population and infrastructure. It brings us back to refitting of rock massifs for fallout shelters requires an increasingly better knowledge of the composition, internal structure, geometry and depth extent of the individual rocks. This paper focuses on the long-term strength of a wide range of rock types that can be refitted for shelters.

KEY WORDS: *rheological properties, rocks, mathematical models, shelters*

1. Introduction

Measurements of soil properties along with detailed observation are what differentiated the emerging discipline of soil mechanics of the early twentieth century from traditional groundworks. These measurements suggested considerable variability in soil properties, not only from site to site and stratum to stratum, but even within apparently homogeneous deposits at a single site. In recent years, our ability to measure the properties of natural soils has expanded rapidly, although it might be argued that our corresponding abilities to understand what many of these measurements mean for engineering predictions, or to deal with the variability among our measurements, have not kept up.

The strength parameters are least variable, while the water contents are most variable. The variability in soil properties encountered on any project is inextricably related to the particular site and to a specific regional geology. It is neither easy nor wise to apply typical values of soil property variability from other sites in performing a reliability analysis. One should no sooner do this than apply 'typical friction angles' or 'typical undrained strength ratios' from other sites. The range of variabilities from one site to another is great, and the data one finds reported in the literature often compound real variability with testing errors. In practice, soil variability measures should always be based on site-specific data [1, 2].

The stress state model in the earth's crust can be constructed using well-known hypotheses. Based on the fact that in the inner regions there is hydrostatic pressure caused by various factors, including the weight of the overlying rock strata, the proportion of stresses due to the weight of the overlying rock strata decreases as you approach the surface and the stress state changes fundamentally. In the direction perpendicular to the free surface, the decrease is relatively stronger than in two horizontal directions. This area is subject to unloading. The stress tensor acquires its direction, and the tensor components acquire different values [3]. The orientation of the tensor in space depends on many factors, in particular, on the possibilities of unloading.

The above experimentally established facts cast doubt on the legitimacy of using the existing stress state hypotheses in solving mining tasks and point out the need for a systematic study of stress fields in various rock masses.

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2. Long-Term Strength Characteristics of the Array

When performing inspection calculations of stability of mine excavations intended as civil defence structures, long-term strength of rocks has to be included. It is usually assessed using the long-term strength coefficient K_{dl}, which characterises the degree of loading on the rock under which the rock can retain its carrying capacity within the specified time period. The coefficient K_{dl} is used in shaft stability calculations [4, 5].

Engineering calculations should consider the lifetime of shafts used as air-raid or bomb shelters to be 5-10 years [6]. The value K_{dl} should be accepted with respect to this excavation lifetime. The lifetime of shafts used as national economy structures is considerably longer, which is why the focus in this case has to be on the smallest possible value of long-term strength of the rock.

Based on many studies [7, 8], long-term strength coefficients K_{dl} have been determined for a wide range of rock types (Table 1). However, all these data are not explicitly bound to a specific time interval.

Table 1.

Long-term strength coefficients for a wide range of rock type

Rock name	Sample compressive strength to uniaxial compression R_{ci}, kgs/cm2	Long-term strength coefficient K_1
1	2	3
Sandstones	900-1800	0.85-0.95
Limestones	500-800	0.85
Coal	100-150	0.85
Siltstones	800-160	0-75
Siltstones	200-700	0.70
Claystones	100-300	0.60
Sandstones	100-600	0.80
Siltstones	80-400	0.70
Claystones	50-300	0.65
Clays	48	0.55
Gypsum	320	0.5
Rock salt	140-220	0.6-0.75
Coal in Permafrost	80	0.5
Shale oil	250-380	0.5-0.6
Silty limestones	75-110	0.76

For reasons of convenience, the K_1 values are shown for lifetimes of 5, 10 and 100 years. When solving problems connected with rock pressures [9], with the exception of the long-term strength coefficient, one has to consider structural characteristics (intensity of cracking, strength of structural blocks, different strength of layers, inclination angles of layer cracks), generally expressed by the structural weakening coefficient K_1.
The expected rock resistance to pressure is calculated using the formula

$$R_{sj} = R_{ci} \cdot K_w \cdot K_l \qquad (1)$$

The generalised indicator $K_{so} \cdot K_{dl}$ characterises the overall weakening of rock as a consequence of structural specificities and geological properties of rocks (loss of strength in time).

Table 2 shows breaking strengths and values of K_{dl} obtained by extrapolating results of laboratory examinations of rock strength characteristics [10], corresponding to shaft lifetimes of 5, 10 and 100 years.

Correct evaluation of rock strength depends significantly on selection of the shape of the cross-section, which has considerable impact on the stability of safety facilities, particularly in rock that tends to protrude.
This is why the following cross-section shapes are recommended when reinforcing parts of mine works [11], which have been selected for establishing safety facilities:

Table 2.

Some coefficients of the rock's lifetime

Name	Rock sample resistance to uniaxial compression R_c, kgs/cm^2	Breaking strength at lifetime, years kgs/cm^2			K_{dl} at lifetime, years		
		5	10	100	5	10	100
1	2	3	4	5	6	7	8
Diabase	2800	2000	2000	1900	0.71	0.70	0.68
Marble	860	720	700	680	0.84	0.83	0.79
Limestones	1100	700	680	610	0.60	0.59	0.53

In rock of the first group (unstable), a zone of cracks with significant penetration into the massif occurs in the area around the mine works. There is movement of the rock at the perimeter of the mine works as it endeavours to fill in the mine works and this creates zones of plastic deformation. In the presence of weak, unstable rock, which tends to squeeze plastically, deformation of the reinforcement occurs and the configuration of the mine works changes, which results in deformation of hermetic safety seals. With regard to this fact, an arced cross-section shape with a circular outline and counter-vault, which is most effective at resisting any protuberance at the bottom, is recommended in rocks of the first group.

In rocks of the second group (average stability) a zone of plastic deformation with miniscule cracks in the cohesive massif occurs around the mine works. Movement of rock at the perimeter of the mine works depends on the strength of this rock, the gradient of the seams, how massive they are and the number of interconnecting seams. In this case an arc-shaped cross-section shape with a circular outline, with counter-vault or without, depending what strength group this rock is closest to: the first or third, is recommended.

In rock of the third group (stable), zones of elastic and plastic deformation occur together with slight movement of rock along the perimeter of the mine works. In this case we recommend an arc-shape cross-section for the reinforcement of the safety facilities, with a circular outline, without a counter-vault.

The stability of safety facilities depends to some degree on correct evaluation of the strength of the surrounding rock, and the most rational cross-section shape of the section of the mine works selected for establishment of a safety facility is chosen in compliance with this evaluation. Furthermore, so that complicated calculations and laboratory modelling is not necessary for determining the angle of internal friction for various categories of rock, we executed its graphic portrayal of its dependence on the limit value of the effect on the service-life of safety facilities.

3. General Conditions for Estimation of Stress-Strain State of the Rock Massif

The mechanism of deformation of a rock mass caused by its destruction is an extremely complex phenomenon. Currently, a large number of measurements of the deformability of the mine workings have been accumulated in the influence zone of sewage treatment works and outside this zone. These measurements include:

- measurement of the convergence of the roof and the soil of the mine working in time;
- measuring the displacement of the sides of the mine working in time;
- measurement of the absolute values of the displacement of the elements of the mine working (roof, soil, sides);
- measurement of displacement rates and their changes in time;
- identification of the dimensions of zones captured by the deformation in front and behind the moving mining faces (of the lava type);
- identification of factors that have the most significant impact on the change in the measured indicators;
- measurement of the relative decrease in the cross sections of the mine workings during a certain service life.

Carrying out such observations requires a lot of labor and is often associated with performing complex instrumental (theodolite) surveys, however, the effect obtained in this case is relatively small, since the dependences of changes in the measured values with time are valid for the local areas, where they were obtained only. The measured values are the result of a complex process of loading the thickness of the rocks surrounding the mine. Actually, the process of deformation of the zones of a massif of a certain order depends on the change in the stress field in the disturbance zone, which in turn is due simultaneously to the following factors:

1. the boundary conditions at the “distant” boundary of “the unbroken massif and the broken massif”, i.e., the type of stress state, the direction of action of the resulting components external to the considered deformable loads to the massif; loads to the massif in various conditions can be included into uniaxial, biaxial and triaxial loading schemes;
2. the determining type of elementary loading at the “distant” boundary (compression, tension, shear, bending);
3. loading rate - the time during which the considered massif is involved in the deformation process, or the intensity of the increase in effort at the “distant” boundary of the massif;
4. conditional linear parameters of the first-order massif involved in the deformation, which are caused, on the one hand, by the features of the geological structure of the region, the physical and mechanical properties of the constituent rocks, and, on the other, by the parameters of the region that caused the disturbance of the previously existing stress-strain state.

These four factors should be considered the main ones responsible for the formation of massifs of various orders of the mine working. Along with them, there may be other factors, in particular, temperature, weather, etc., which, when considering a rock mass, for example, in the conditions of permafrost or on the surface of a pit, can transfer into the category of basic conditions for these conditions.

Thus, the combination of these factors, the duration of their effect and the sequence of entry are decisive for the type of loading mechanism and the formation of massifs of various orders.

In accordance with the foregoing, the same result can be achieved with a different combination of factors determining the destruction. It may turn out that the limit state is reached, other conditions being equal, by changing only one factor, or, conversely, the limit state occurs with a simultaneous regular increase in a few factors. That is why it was pointed out above that insufficient measurement efficiency of only the final result of the massif loading, since the reasons and quantitative assessment of the phenomenon in such measurements remain unclear. In this regard, there is currently no clear understanding of the formation of rock strikes and emissions, and at the same time about ten theories of rock pressure coexist.

The formation in the process of loading a certain region of massifs of different orders, which are qualitatively different from each other, requires appropriate approaches to their study. At present, such paths have already been outlined, however, studies are carried out in a fragmented manner, there is no single sound methodology; often there is no clear idea of the final goal, or it is not set at all, and the researcher is limited to the task of obtaining some kind of intermediate result.

4. Conclusions

Based on the formulated ideas about the massifs of rocks and the mechanism of formation of qualitatively different massifs, we will evaluate the set of studies necessary for the quantitative assessment of the stress-strain state of the massif, which would be sufficient for a reasonable judgment on the result of the behavior of the rocks and on the basis of which it would be possible to predict the behavior of the massif of rocks with the corresponding parameters of engineering structures (development system, mining, pillar, side or ledge quarry, well, etc.), as well as mining machinery and technology.

To characterize the entire complex of rocks involved in the loading process, you need to know the following:

1) the general geological structure of the area of the alleged mining operations to classify the natural massif as homogeneous or stratified;
2) the stress state of the rocks in the undisturbed massif (direction and magnitude of the main stresses);
3) indicators of physical and mechanical properties of rocks;
4) for heterogeneous and stratified natural massifs, the characteristic of heterogeneity;
5) building a model of the natural massif before mining;
6) development of a mechanical model of loading of rock massif during mining operations.

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References

1. **Pruška, J.,** Neural Networks in Back Analysis of Tunnels, Durability of Critical Infrastructure, Monitoring and Testing Proceedings of the ICDCF 2016. Springer Nature Singapore Pte Ltd., 2017. ISSN 2195-4356. ISBN 978-981-10-3246-2.
2. **Kachanov, L.M.,** Introduction to Continuum Damage Mechanics, Martinus Nijhoff Publishers, Dordrecht, Netherlands, 1992
3. **Cundall, P.A.,** A Computer Model for Simulation Progressive Large Scale Movements of Blocky Rock Systems. Symposium of the International Society of Rock Mechanics, 1971
4. **Pruška, J.; Šedivý, M.,** Prediction of Soil Swelling Parameters, Procedia Earth and Planetary Science. 2015, 15 229-234. ISSN 1878-5220.
5. **Kravcov, A.; Morozov, N.; Svoboda, P.**; Pospíchal, V.; Zezulová, E., Quality assessment of bored pile foundations by a set of nondestructive testing methods, 2019 International Conference on Military Technologies (ICMT). IEEE (Institute of Electrical and Electronics Engineers), 2019. p. 87-91. ISBN 978-1-7281-4594-5.
6. **Haramy, K.Y., Morgan, T.A., DeWaele, R.E.,** Method for estimating western coal strengths from point load tests on irregular lumps, 1982
7. **Hilar, M.; Pruška, J.,** Statistical Analysis of Input Parameters Impact on the Modelling of Underground Structures, Acta Polytechnica. 2008, 48(5), 3-8. ISSN 1210-2709.
8. **Kravcov, A.; Morozov, N.; Svoboda, P.; Pospíchal, V.; Zezulová, E.,** Quality assessment of bored pile foundations by a set of nondestructive testing methods, 2019 International Conference on Military Technologies (ICMT). IEEE (Institute of Electrical and Electronics Engineers), 2019. p. 87-91. ISBN 978-1-7281-4594-5.
9. **Svoboda, P.; Kravtsov, A.,** Mathematical Model of Seismoexplosion in Tunnel Surrounding, Applied Mechanics and Materials. 2015, 731 1021-1026. ISSN 1662-7482.
10. **Kravtsov, A.; Svoboda, P.; Pospíchal, V.; Zdebsky, J.,** Experimental Studies on Process of Transition of Explosion to Deflagration due to Methane Gas Explosion in Underground Structures, ICMT 2015 - International Conference on Military Technologies 2015. Rio de Janeiro: IEEE Institute of Electrical and Electronics Engineers Inc., 2015. pp. 125-133. ISBN 9788072319763.
11. **Hilar, M.; Pruška, J.,** Statistical Analysis of Input Parameters Impact on the Modelling of Underground Structures, Acta Polytechnica. 2008, 48(5), 3-8. ISSN 1210-2709.
12. **Cibulová, K.** 2017. The Mobility during Crisis Situations. In: Structural and Mechanical Engineering for Security and Prevention ICSMESP 2017. Switzerland: Trans Tech Publications, 236-241. ISSN 1662-9809.
13. **Cibulová, K.** 2018. Comparative Measurement of Instruments Used for Evaluation of Terrain Trafficability. Transport Means 2018. Kaunas: Kaunas University of Technology, 1147-1150. ISSN 1822-296X.
14. **Hošková-Mayerová, Š.; Talhofer, V.; Hofmann, A.**; et al. 2013. Mathematical Model Used in Decision-Making Process with Respect to the Reliability of Geodatabase, Advanced Dynamic Modeling of Economic and Social Systems, Book Series: Studies in Computational Intelligence, vol. 448, 143 p.
15. **Hošková-Mayerová, Š.; Talhofer, V.; Hofmann, A.**; et al. 2013. Spatial Database Quality and the Potential Uncertainty Sources, Advanced Dynamic Modeling of Economic and Social Systems, Book Series: Studies in Computational Intelligence, vol. 448, 127 p.