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DETERMINATION OF PHYSICAL AND MECHANICAL PROPERTIES OF SEDIMENTARY ROCKS OF CARBONIFEROUS AGE

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Abstract. Laboratory measurements on sandstones and claystones of the Carboniferous age from Kladno coal district were carried out to determine main physico-mechanical parameters of these rocks. The laboratory of the IRSM AS CR determined both the descriptive (specific and unit weight, porosity, humidity, etc.) and mechanical properties (strength and deformation characteristics). Results are synoptically tabulated.

Keywords: Rock mechanics, rock testing, rock properties.

1. Introduction

A basic precondition for a successful solution of theoretical and connected problems of rock and rock mass mechanics is the knowledge of physical and mechanical properties of rocks and determination of mechanical characteristics of the rock massif. This is important, above all, for the description and understanding of the basic mechanical processes induced by mining activities. The description of mechanical properties of rock sampled from the hanging wall of the mine Kladno coal seam is therefore used for complex processing of the situation and for the preparation of the local and temporal prediction of the occurrence of rock bursts.

2. Taking and Preparation of Samples

For laboratory testing of physical and mechanical properties, which were intended to yield, in addition to deformation (stress–strain) characteristics, also the strength at various stress conditions, the samples were taken in undisturbed form from the bedrock and the hanging wall of mine drifts. The preparation of treatment of rock samples were carried out in the Laboratory of rock mechanics of IRSM AS CR according to standard methodics.

Samples from the immediate overburden of the main Kladno seam were taken in the northern part of the shaft pillar, in the hanging wall of the newly driven drift CH 3100 at the 10^{th} floor. At the same floor, in the southern part of the drift 3001, samples were taken from the bedrock of the coal seam.

In the hanging wall, there are arkosic sandstones to arkoses and in the bedrock, an atypical material from the upper part of the underlying breccia had to be dealt with. Visually, the material lack any tuffitic admixture characteristic for tuffitic sandstones to tuffites from the bedrock of the seam ("whetstone", "whitestone").

Samples from the 7th floor (100 m above the exploited seam) were taken at the buffer stop in the by–pass of the shafts Mayrau and Robert in the distance of about 50 m from the both shafts. These samples were sandstones of varying grain size from lowest positions of the Nýřany layers. The choice of rock types was in agreement with possibilities of macroscopic resolution [Šašek, 1978] and the evaluation and comparison of test results were carried out according to provisions of the Czech standard ČSN 72 1001/1970. Thus, the grain size was

for claystone	$< 0{,}002$ mm	(A)
for siltstone	0,002 – 0,063 mm	(EC)
for fine–grained sandstone	0,063 – 0,25 mm	(E)
for medium–grained sandstone	0,25 – 1,00 mm	(G)
for coarse–grained sandstone	1,00 – 2,00 mm	(J)

The clear–cut, neat types are fairly rare. Usual samples concern various transitory types, in spite of the fact that we tried to prepare, for testing, as isotropic material as we could.

It is evident that parameters of rocks established in a laboratory on test specimens may exhibit some deviations from values obtained in the rock massif, because tectonic and deposition conditions cannot be fully respected in the laboratory.

Although several sediments are typical examples of inhomogeneous and anisotropic matter, the tests were mostly carried out perpendicularly to layers of the sampled material. The reason is that the Carboniferous of Kladno is deposited almost horizontally. As the tested rock samples were loaded (during compression tests) perpendicularly to layer planes, the axial deformation is understood as vertical (to layers) and the cross deformation is taking place in the sense (direction) of layers.

Test specimens were worked into precise and regular geometric shapes according to the test requirements (prism, cube, little beam). The faces were ground for uniform load distribution.

Measurements were carried out on presses with maximum load force of 3000 kN (compression, traversal tension, etc.) or 300 kN (simple tension).

3. Physical Properties

Physical properties can be divided, according to their character, into three groups [Hoffrichter, 1977]:

a) descriptive (physical properties),
b) technical,
c) physico–mechanical.

The group of descriptive properties is fairly sufficient to the purpose of the evaluation of mechanical properties. From these properties, the specific and volume weight (mass), humidity, absorption capacity, and porosity have been determined.

Tests were carried out according to valid Czech standards and internal standards of mining and construction branches.

However, it is very difficult to discuss the original physical condition of the rock (i.e. the condition corresponding with natural deposition). The handling of rock, its transport to the laboratory, processing (cutting under water flushing) modify considerably the condition of rock. It results thus evidently that values of mechanical characteristics obtained by laboratory measurements hold only for most coherent bodies (specimens), minimally affected by weakening faces.

Just to illustrate the effect of sample processing, values of humidity may be quoted. The humidity of rock is namely one basic descriptive property required not only for comparison of individual rock types, but also for the evaluation of mechanical or technological characteristics. In so doing, it should be differentiated, whether we have to deal with natural humidity of the rock or with the actual condition of the specimen at the time of the respective rock test.

The humidity affects significantly the compression strength of carboniferous rocks. It results from laboratory tests carried out, for example, on the Mining University iv Ostrava [Vavro, 1964], that the increasing humidity reduces the simple compression strength of carboniferous rocks by 0–30 %, compared with that of the rocks in natural deposition (in situ). The value of this deviation depends also on the grain size and the quality of the cement (binder) of tested rocks.

The affect of humidity on the simple compression strength will be especially felt in the neighbourhood of water–bearing fault zones.

The determination of humidity, carried out immediately after taking the sample within the mine, resulted in the value of 7,36 %. After the necessary treatment and preparation of samples, this value dropped in order and then did not change practically during the entire time of testing. Thus, it may be said that all measurements were carried out at constant humidity and the obtained values are comparable though somewhat higher than they would be at natural conditions.

Values of physical properties, tabulated in Tab. 1, are mean values of a series of measurements of individual types of carboniferous rocks.

4. MECHANICAL PROPERTIES

Such properties of rocks are understood as mechanical, which express the mechanical manifestation of the rock and rock massif in space and time. We can characterize the mechanical manifestation of given rocks, as a statistical entirety of local and consecutive processes and states.

All rocks have quite complex physical and mechanical properties, which change rapidly both within the range of numerical values characterizing certain properties and at alteration of natural conditions, where qualitatively new properties may be acquired. Thus, the physical and mechanical properties of individual rocks or the whole massif, resp., must be estimated as a complex.

Due to considerable heterogeneity of rocks and variability of their mechanical properties, test results from one or a few specimens cannot be considered satisfactory. According to the internal standard ON 44 1110, values of mechanical

TAB. 1. Summary of ascertained values

a) Physical properties

petrogr. type	level	spec. weight ρ_s (g/cm^3)	volume weight ρ_0 (g/cm^3)	mois-ture w (%)	absorp-tivity NV (%)	poro-sity p (%)
hanging wall						
J	7.	2,658	2,389	0,13	5,87	10,12
G	7.	2,670	2,333	0,66	6,63	12,62
E	7.	2,389	2,658	0,37	6,09	10,12
EC	7.	2,700	2,377	0,38	5,10	11,96
G	10.	2,662	2,341	0,18	6,37	12,06
J	10.	2,657	2,328	0,15	6,86	12,38
coal**)						
A	10.	2,660	2,430	2,75	—	11,20
U	10.	1,430	1,260	13,00	—	20,00
Tš	10.	2,510	2,480	2,80	—	23,00
B	10.	2,510	2,420	2,96	—	25,60
under.*)						
L	10.	2,680	2,413	0,16	4,07	9,96
A		2,740	2,560	0,67	23,00	7,40

b) mechanical properties

petrogr. type	level	simple compress. σ_{pd} (MPa)	shear τ_{pst} (MPa)	simple tension σ_{pt} (MPa)	transvers. tension σ_{ptp} (MPa)	tension by spatial bending σ_{top} (MPa)	rheolog. compress straight σ_R (MPa)	σ_R/σ_{pd}
hanging wall								
J	7.	5,07	1,28	0,34	0,80	0,62	3,87	0,76
G	7.	17,17	2,80	0,48	0,96	1,20	14,90	0,88
E	7.	27.81	5,48	0,77	1,58	2,88	23,51	0,84
EC	7.	42,41	8,30	2,50	3,87	7,39	40,57	0,96
G	10.	11,48	3,55	0,43	1,28	1,80	13,13	1,14
J	10.	6,99	1,83	0,13	0,60	1,17	6,36	0,91
coal**)								
A	10.	44,70	4,90	1,74	—	—	—	—
U	10.	13.50	2.69	0.42	—	—	—	—
Tš	10.	45,95	3,35	2,46	—	—	—	—
B	10.	48,37	2,94	0,59	—	—	—	—
under.*)								
L	10.	35,29	13,57	9,47	1,40	5,43	—	—
A		41,76	—	—	—	—	—	—

c) deformational properties

petrogr. type	level	strain's modulus E_d (MPa)	be valid from – to E_d (MPa)	Young's modulus E (MPa)	Poisson's ratio μ
hanging wall					
J	7.	2620	1,21–6,11	4466	0,37
G	7.	5370	6,87–10,62	9602	0,42
E	7.	6320	5,22–11,09	9792	0,22
EC	7.	9676	12,16–24,91	15326	0,21
G	10.	1357	0,94–2,18	2080	0,45
J	10.	628	0,44–1,25	1206	0,39
under.*)					
L	10	2352	1,25–3,13	3045	0,49

*) [Přibyl,1971]; **) [Polák, 1964]

description of rock
J – coarse-grained sandstone
G – medium-grained sandstone
E – fine-grained sandstone
EC – siltstone
A – claystone
U – coal
$T_š$ – arenaceous marl
B – shale
L – fine-grained conglomerate

properties are defined as arithmetic mean from at least five test specimens, prepared from one rock sample. Requirements concerning the size of the specimen and the number of test bodies, which must be prepared for tests, result from this standard condition.

Owing to the fact that the value of mechanical properties is derived from a random selection of samples, this value should be evaluated as a statistical quantity, i.e. by determination of basic characteristics of a statistical set. Thus, the values are estimated according to the Gauss–Laplace function [Pauli, 1991].

For the evaluation of tests, the mean value is quoted as resulting value:

$$\overline{R} = \frac{1}{n} \sum R_i \,,$$

standard deviation

$$s = \sqrt{\frac{\sum (R_i - \overline{R})^2}{n}} \,,$$

coefficient of variability

$$v = \frac{s}{\overline{R}} \,,$$

and dispersion variance

$$P = \frac{R_{\max}}{R_{\min}} \qquad R_{\max,\min} = \overline{R}\big(1 \pm 2\,\frac{v}{\sqrt{n}}\big)\,.$$

In this way, statistical values of strength, which were used as representative for further application, were obtained.

The measured values are synoptically tabulated in Tab. 1, where – for better orientation – also values of mechanical properties of coal and partings, obtained from earlier measurements [Polák, 1964] have been added. Quoted is also the single known value of simple compression strength of claystone, which occurs, as well, in the overburden of the seam [Přibyl et al., 1971]. As the simple compression strength measurements were carried out on a specimen with the slenderness ratio 1, the tabulated values was converted to the slenderness ratio 2 to correspond with other values according to the formula

$$R_d = R_D\,\frac{7 + 2\,\frac{d}{h}}{9}\,,$$

where

$R_D = \sigma_{pd}$ for the sample with $h/d = 1$,
R_d = transformed σ_{pd} [Pauli, 1991].

From the viewpoint of susceptibility of rock bursts, the following properties are actually considered important:

Deformational properties (at uniaxial and multiaxial compression). With increasing stress/strain or elasticity moduli, an increasing susceptibility of rocks towards bursting can be expected. The value of Poisson ratio is considered as well. The elastic behaviour (accumulation capacity of elastic energy) and the brittle failure are favourable for the occurrence of rock bursts.

Strength properties. For example, the ratio of compression strength to the transversal tensile strength (coefficient of brittleness) may be considered. As higher is this coefficient, as higher is the risk of the occurrence of rock bursts. The range of values calculated in our experiments varies from 6 to 23, the highest value appertaining to the underlying fine–grained conglomerate [Vydra, 1994].

However, it should be stressed that such considerations and calculations based on mere comparison of the investigated parameters may lead to considerably distorted results. There are many different reason for such a distortion. The most frequent is the uncertainty, whether always exactly the same rock types are compared, with the same humidity, or, which is also very relevant, whether the mechanical characteristics obtained at varying kinds of stressing are comparable.

A most complex picture of the strength character of rock is obtained from the limiting envelope of Mohr circles. This condition of limiting states originated from the development of the Coulomb condition of maximum angle of internal friction (ϕ). It is expressed graphically as a common tangent of Mohr circles.

From the graphical construction of Mohr's strength envelope, data of the shear strength are frequently used as data for plotting the point directly on the axis of shear stresses τ.

Figures No. 1 and 2 illustrate the Mohr envelopes for two rock types, the coarse–grained sandstone (J) and the powder–grained sandstone (EC).

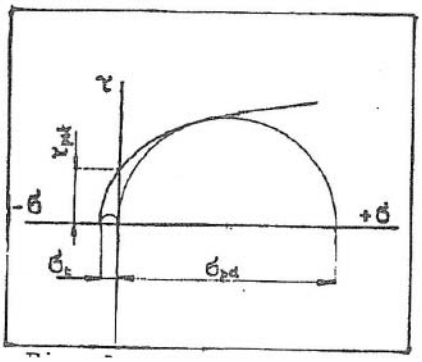

FIG. 1: Petrographic type J

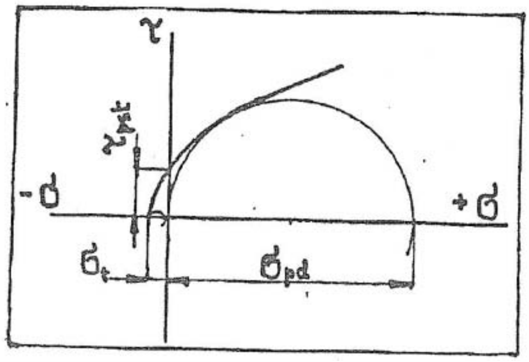

FIG. 2: Petrographic type EC

The characteristic mechanical properties of rock is expressed, in principle, also by its internal friction angle (ϕ). Its value is directly proportional to the strength of rock and thus also to the degree of tensile resistance, and indirectly proportional to the stress, which acts on the rock.

The value ϕ_0 is indicated as representative for ϕ, corresponding to the stress $\sigma = 0$. Thus, the internal friction angle is the angle of the tangent to the Mohr envelope of limiting circles at point $\sigma = 0$.

For the investigated rocks of Kladno overlying sandstones, the internal friction angle varied within $60° - 70°$. definitely (for example) for the medium–grained sandstone from th 10^{th} floor it was $68°05'$ and for the same type from 7^{th} floor – $71°31'$.

5. CONCLUSIONS

Strength characteristics by laboratory measurements confirm the possibility of occurrence of rock bursts, which is also confirmed by the susceptibility to brittle failure. It has been also established that the long–term strength does not, in principle, differ from the short–term strength.

It should be stated, in conclusion, that the solution of problems associated with causes of occurrence of rock bursts in mines is a multidisciplinary problem, which requires the acquisition of large quantity of information, not only from the sphere of mechanical properties of rocks.

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