MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL TECHNICAL UNIVERSITY
“DNIPRO POLYTECHNIC”

PHYSICS OF ROCKS AND PROCESSES

METHODICAL RECOMMENDATIONS TO PERFORM LABORATORY AND PRACTICAL TASKS ON “PHYSICS OF ROCKS” SUBJECT

Dnipro
NTU “Dnipro Polytechnic”
2020

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ДНІПРОВСЬКА
ПОЛІТЕХНІКА
1899

КАФЕДРА
БУДІВНИЦТВА,
ГЕОТЕХНІКИ
І ГЕОМЕХАНІКИ

FACULTY OF CONSTRUCTION
Department of Construction, Geotechnics and Geomechanics

PHYSICS OF ROCKS AND PROCESSES

METHODICAL RECOMMENDATIONS TO PERFORM LABORATORY AND PRACTICAL TASKS FOR STUDENTS OF 184 MINING SPECIALISM AREA ON “PHYSICS OF ROCKS” SUBJECT

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2020

Soboliev, V. V. Physics of Rocks and Processes: Methodical recommendations to perform laboratory tests and practical tasks for students of 184 Mining specialism area /V.V. Soboliev, O.V. Skobenko, N.V. Khoziaikina. - Dnipro: NTU “Dnipro Polytechnic”, 2020. – 32 pp.

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It has been recommended for publication by the editorial National Technical University “Dnipro Polytechnic” (Protocol № 1 of 27.01.2020) on the submission of the Department of Construction, Geotechnics and Geomechanics (Protocol № 5 of 7.11.2019).

The methodical recommendations have been submitted to perform laboratory and practical tasks on the discipline “Physics of Rocks” for students of specialism area 184 “Mining”.

The structure and form of the presented materials are focused on independent preparation for laboratory activities under guidance of academics, which allows the most effective studying and understanding the physical and chemical nature of the processes occurring in rocks.

The methodical recommendations include solving calculation problems under the guidance of academics as well as during independent work.

Solving calculation problems is intended to the analysis of rock characteristics and understanding the nature of physical and technical regularities of such basic technological processes of mining production as destruction, excavation, transportation, crushing, and preparation.

Responsible for the issue is S.M. Hapieiev, the Head of the Department of Construction, Geotechnics and Geomechanics, Doctor of Technical Sciences, Associate Professor.

CONTENT

INTRODUCTION

The methodological recommendations describe the methods for students to carry out laboratory tests and calculation tasks on the “Physics of Rocks” Subject.

Basic idea of the laboratory works is to master basic information about porosity as one of the fundamental characteristics of rocks as well as about physical, mechanical and acoustic properties of rocks.

The basic idea of the laboratory activities is as follows:

- carrying out laboratory tests following the accurate scheme determined according to the specific procedure; and
- processing the experimental results, i.e. obtaining the parameters of rocks characterizing their physical properties.

The tasks which should be performed by a student during the laboratory activities:

a) study theoretical material connected with the laboratory topics;

b) carry out the laboratory tests;

c) perform calculations concerning the main parameters and characteristics of rocks;

d) substantiate the calculations and make up conclusions to the laboratory activities;

e) prepare a report on thecarried out laboratory activities and calculation tasks.

Requirements for carrying out and reporting on the laboratory activities

The technique to carry out laboratory activities on “Physics of Rocks” subject

1. Instructions for students.

1.1. Studying theoretical material on the relevant laboratory test.

1.2. Taking notes of the laboratory activity material inclusive of:

- title of the laboratory test;
- purpose of the laboratory test;
- general information (theoretical material – calculation formulas, definitions, stages of work, charts and tables); and

1.3. Review of control questions.

Note. The abstracted (printed or manuscripted) material of the laboratory test is submitted to the academic at the beginning of the class on A4 sheets.

2. Carrying out laboratory activity and obtaining results.

2.1. Processing of the laboratory test results and obtaining of the required indices and graphs.

2.2 The processed results as well as the obtained indices and graphs are added to theoretical material of laboratory activity on A4 sheet.

2.3. The student makes up a conclusion to the laboratory test.

2.4. The student calculates tasks if it is required.

Note. The laboratory task material, submitted on A4 sheets, is filed.

3. Defending of the laboratory test:

3.1. The collected material of the laboratory test is submitted to the academic.

3.2. A student defends the submitted material (i.e., he/she answers control questions; understands and can explain calculations; uses the terms properly; knows the calculation formulas, values of measurement and stages of the work).

3.3. The defence is performed either in writing or orally.

4. At the end of academic quarter, a student collects all the defended laboratory activities, adds a title page (see Appendix 1) and staples them or files.

5. If a student did not report on carrying out of the laboratory activities, or did not defend them, he/she is not allowed to take an exam (or a credit).

6. Technical requirements to the format of laboratory activities.

Languages: Ukrainian or Russian. Theoretical, calculating and graphic materials as well as tables are submitted either in a printed form or as a manuscript on A4 sheets. The text should be printed in black on a white paper on one side of the sheet. Font is Times New Roman, font size is 12. Line spacing is single. All margins are 2 cm.

Laboratory work # 1

Determining rock strength on uniaxial compression

1. Objective is to study the method of determiningrock strength on uniaxial compressionby means of independent test in go several samples; to look through the existing State Standards of Ukraine (State Standard) for the determinations and to study the rock classification in terms of a strength coefficient.

2. General information

Rock strength on uniaxial compression is the rocks characteristic widely used in various mining calculations. This indicator correlates well with all technological processes of mining, i.e. excavation, supporting, drilling, rock destruction by explosion as well as with such physical processes as rock pressure formation, rock mass boundary shears, stability of mine workings, floor rock heaving, sudden emissions of coal, rocks and gas etc. The coefficient of rocks strength, proposed by Professor M. M. Protodiakonov, is closely connected with rock strength. The coefficient is widely used in mining industry. Value of the coefficient, being rock strength on the uniaxial compression, is decreased by 100 or 10 times depending upon measurement units:

$$f_{str} = \frac{\sigma_{str}}{100(10)}, \qquad (1.1)$$

where f_{str} is strength coefficient on the scale by M. M. Protodiakonov; σ_{str} is rock on the uniaxial compression, kg/cm^2, MPa.

The repeated rock tests have shown that the value of the strength coefficient can be rounded up/down to the whole numbers with no specific errors. In this context, a set of **1** to **20** values has been obtained. It has been determined that the strength coefficient is the **rock technological characteristic** which can be used to standardize (and evaluate):

- lab our costs to perform certain operations within rocks of the determined strength;
- calculation of drilling and blasting parameters; and
- selection of support, machines, and mechanisms.

For these reason, fractional values of the strength coefficient have been introduced in the area of low strength values, namely 0.3; 0.5; 0.6; 1.0; and 1.5.

From the area of high values, Professor M. M. Protodiakonov excluded the generalized 7, 9, 11, 12, 13, and 14 values as well as all intermediate values between 15 and 20. Currently, it is expedient to preserve each strength coefficient from 7 to 20 within the classification due to the complexity and improvement of the mineral mining technique. However, indicator 20 remains the upper limit of the classification despite the strength may exceed 2000 kg/cm^2.

Rock strength on uniaxial compression is the maximal (critical) stress at whichrocks destruction takes place.

According to M. M. Protodiakonov, the ***strength coefficient*** is one hundredth (or tenth) of the strength on uniaxial compressionbeing technological characteristic rather than a physical and mechanical one. The rock strength on uniaxial compression is regulated by the State Standards of Ukraine (i.e. SSU) 21153.1-7-84 ‘Rocks. Test methods.’ According to the State Standards, cubic or cylindrical rock samples should be prepared for the tests. Moreover, the samples should also meet the requirements of the State Standards: 50x50x50 mm cubes, and $h/d=1$ cylinders with the polished surfaces. Deviations from these dimensions should not exceed ± 5%, and the convexity of the end – 0.3 mm. The tests are carried out using hydraulic presses as many times as it is necessary to obtain reliable strength values for each rock type.

Using probability theory, the number of rock samples is determined by the formula

$$n = t_\alpha^2 \cdot \left(\frac{W}{q}\right)^2, \qquad (1.2)$$

where t_α is a Student` coefficient. It is selected from the Table depending on the required accuracy of the determinations. For the majority of engineering calculations, the accepted probability is 0.95; then $t_\alpha = 1.96$; W is the coefficient of variation, %; and ***q*** is the acceptable deviation, %.

3. Procedure

1.Set the rock sample between two steel plates in the centre of the press Fig.1.1.

2. Turn off oil cock; use a pump lever increase pressure evenly up to the sample destruction (the required loading rate is 5-10 kg/cm^2). Record maximum pressure at the moment of destruction using a gauge hand.

3. Carry out the test again; record the result in Table 1.1.

4. Carry out test two. Record it result in Table 1.1. (calculations are performed for ten values).

5. Calculate the destructive force as follows

$$P_{\max} = a \cdot 50 \cdot b, \qquad (1.3)$$

where ***a*** is the manometer indicator, kg/cm^2, **50** is a piston area, cm^2; and ***b*** is the manometer scale division.

6. Calculate the rock strength (i.e. critical stress) as follows

$$\sigma_{str} = \frac{P_{\max}}{F}, \qquad (1.4)$$

where ***F*** is cross-sectional area of the rock sample, cm^2.

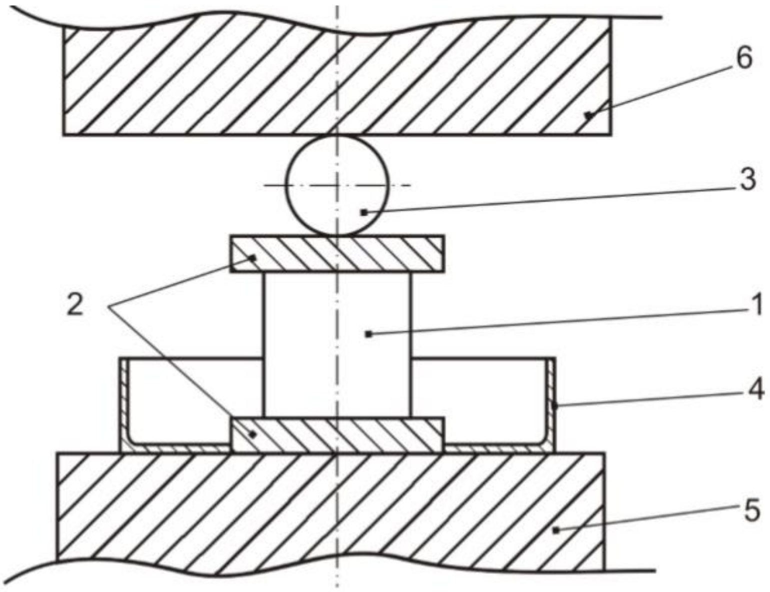

Fig. 1.1. The test scheme: 1 – rock sample; 2 – steel inserts; 3-centering steel ball; 4 – chute; 5 – pressure plate; and 6 – base plate

7. Determine average value σ_{str} of the ten values

$$\sigma_{str}^{av} = \frac{\sigma_{str}^{1} + \sigma_{str}^{2} + \ldots + \sigma_{str}^{10}}{10}. \qquad (1.5)$$

8. Determine the average quadratic deviation (i.e. standard deviation):

$$S = \sqrt{\frac{\sum_{1}^{n}\left(\sigma_{str}^{av} - \sigma_{str}^{i}\right)^{2}}{n-1}} = \sqrt{\frac{\left(\sigma_{str}^{av} - \sigma_{str}^{1}\right)^{2} + \left(\sigma_{str}^{av} - \sigma_{str}^{2}\right)^{2} + \ldots + \left(\sigma_{str}^{av} - \sigma_{str}^{10}\right)}{9}}. \qquad (1.6)$$

Note: if n<10, then (1.6) formula is added by n.

9. Determine variation coefficient W, %:

$$W = \frac{S}{\sigma_{str}^{av}} \cdot 100. \qquad (1.7)$$

10. Specify the number of the tests according to the formula (1.2), and taking the required value ***q***.

The measurement results are recorded in Table.1.1.

Table 1.1

The results of rocks test as for the uniaxial compression

#	Mano-meter readings, kg/cm^2	Destructive force P_{max}, kg	Rock strength, σ_{str}, kg/cm^2	Average value σ_{str}^{av}, kg/cm^2	Standard deviation, S, kg/cm	variation coefficient, W, %	Strength coefficient, f_{str}
1.							
2.							
…							
…							
10.							

PAY ATTENTION! The dimensions are transformed in the SI-system as follows:

- Force ***P***, measured in kg while calculating, must be multiplied by 9.81 or 10; then the result of the destructive force will be measured in ***N*** (Newton);

- Stress σ is expressed in Pascal (Pa) or mega Pascal (MPa)

σ [kg/cm^2]$\cdot 10^5 = \sigma$ [Pa].

For example: Force ***P*** = 10 kg = 100 N;

Stress σ = 450 kg/cm^2 = 450·105 Pa = 45.0 MPa.

4. Test questions for Laboratory work # 1

1. What is the rock strength on uniaxial compression?
2. What is the practical use of rock strength on uniaxial compression?
3. What is the rocks strength coefficient? How can it be determined?
4. What is the number set the strength coefficient corresponds to?
5. Are there any requirements to the shape and size of the rocks samples selected for testing? If so, what are the requirements?
6. How is the destructive force calculated?
7. What formula is used to calculate the critical stress?
8. What are the units to measure rock strength?

Laboratory work # 2

Determining complete rock resistance to shear (coefficient of adhesion and internal friction angle)

1. Objective is to study the method of determining rocks strength for shear (shear) in terms of testing several samples and to make a strength passport.

2. General information

Rock strength during shear is the shear resistance depending on the two physical factors: ***internal friction and adhesion.***

Internal friction($\sigma_n \cdot tg\varphi$) is a result of interaction between mineral particles under deformation being proportional to the normal stress caused by external load.

Adhesion(C) is the part of the shear resistance not related to the stress caused by external load; it is determined only by the molecular and structural connections. Adhesion is a constant value for the given rock.

Total shear resistance (τ) is expressed as the sum of internal friction and adhesion:

$$\tau = \sigma_n \cdot tg\varphi + C, \tag{2.1}$$

where $tg\varphi$ –internal friction coefficient; and φ – internal friction angle.

Internal friction coefficient $tg\varphi$ is the coefficient of proportionality between the increment of destructive normal stresses and tangential stresses.

The equation (2.1) contains two unknown values ***C*** and φ. To solve the equation, it is necessary to test at least two samples under different load conditions (at two different shear angles); then we obtain a system of two equations which can be solved.

The special steel matrices are used for the tests (Fig. 2.1) to place the sample. Load under the press is carried until the sample is destroyed.

Since the matrices develop conditions approaching the sample destruction up to the conditions of pure shift (i.e. shear deformations occurring under a homogeneous stress state) on the inclined plane, the destructive force ***P*** (press pressure) can be decomposed into two components –normal and tangent (Fig. 2.1).

3. Procedure

Following the scheme shown in Fig. 2.1, the sample is placed in the matrix under the press where it is loaded up to its destruction; manometer is used to record the maximum pressure values in the hydraulic system of the press **(*a*, kg/cm^2).**

Calculate destructive force ***P***:

$P = a \cdot 50 \cdot b$ – if a shear angle is 35^0;

$P' = a' \cdot 50 \cdot b$ – if a shear angle is 55^0;

where ***a*** is an indicator of manometer; ***b*** – a scale division of the manometer; ***50*** – a press piston area, cm^2.

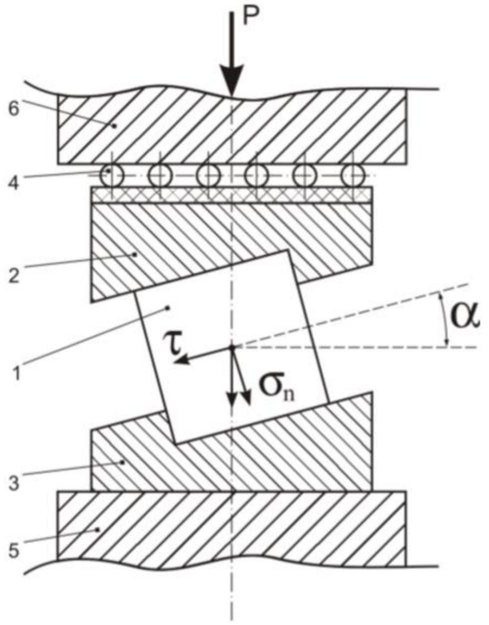

Fig. 2.1. The test scheme: 1 –rock sample; 2 – upper steel insert; 3-lower steel insert; 4-hinge insert; 5 –base plate; and 6-pressure plate

The normal σ_n and τ tangential stresses are calculated taking into account the inclination angle of the sample in the matrices (the inclination angles in matrices are 35^0 and 55^0).

If shear angle is 35^0then:

$$\sigma_n^{35} = \frac{P}{S}\cos 35^0\,; \tag{2.2}$$

$$\tau_n^{35} = \frac{P}{S}\sin 35^0\,. \tag{2.3}$$

If shear angle is 55^0then:

$$\sigma_n^{55} = \frac{P'}{S}\cos 55^0\,; \tag{2.4}$$

$$\tau_n^{55} = \frac{P'}{S}\sin 55^0\,. \tag{2.5}$$

where ***S*** is a cross-sectional area of the sample (***S*** = 25 cm^2).

Thus, the two tests make it possible to make a system of two equations:

$$\begin{aligned}\tau^{35} &= C + \sigma_n^{35} \cdot tg\varphi,\\ \tau^{55} &= C + \sigma_n^{55} \cdot tg\varphi.\end{aligned} \tag{2.7}$$

Solving this system of equations helps us calculate φ and ***C***:

$$tg\varphi = \frac{\tau^{35} - \tau^{55}}{\sigma_n^{35} - \sigma_n^{55}}. \tag{2.8}$$

After $tg\varphi$ substitution in one of the equations (2.7), ***C*** value is calculated

$$C = \tau - \sigma_n \cdot tg\varphi. \tag{2.9}$$

To control the ***C*** value, equation two of the system (2.7) is calculated as well (2.7). If the experiments have been conducted correctly, then both values of ***C*** will be similar.

Analytical value of the uniaxial compressive strength is calculated as follows

$$R_{str} = 2 \cdot C \cdot ctg\left(45 - \frac{\varphi}{2}\right). \tag{2.10}$$

The *C*, φ, and R_{str} values, obtained from the experiments, are used to make strength passport of(Fig. 2.2).

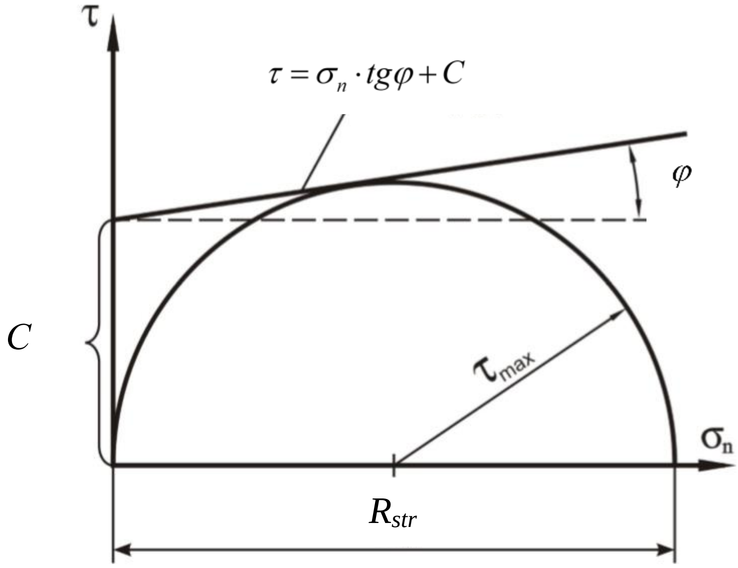

Fig. 2.2. Example of strength passport making

The strength passport is a tangent drawn to the circumference of the maximum tangential stresses ($\tau_{\max} = \frac{R_{str}}{2}$ ***in this case) at an angle being equal to the angle of internal friction, taking into account the value of adhesion (C) of the rock.***

All calculations are performed in a copybook and the calculated values are recorded in Table 2.1.

Table 2.1

The results of rocks sample shear tests

Angle of matrix inclination	Manometer readings, ***a***, kg/cm^2	Destructive force ***P***, kg	Shear area of sample, cm^2	Tangential stress ***τ***, kg/cm^2	Normal stress σ_n, kg/cm^2	Angle of internal friction, φ, degree	Adhesion indicator ***C***, kg/cm^2
35^0							
55^0							

The calculations can be performed using either the SI-system or the technical system of units.

4. Test questions for Laboratory work # 2

1. What are the physical parameters characterizing rock shear strength?
2. What is internal friction; what is the formula to calculate it?
3. What is friction coefficient?
4. What is the formula to determine the angle of internal friction?
5. What is adhesion?
6. What is the physical difference between adhesion and internal friction?
7. What is the complete shear resistance?
8. How can normal and tangential stresses be calculated?
9. What is the purpose to test the samples at different shear angles?
10. How to calculate the value of rock strength on the uniaxial compression?
11. What is a strength passport?
12. What is characterized by a common point belonging to a tangent and a circle of the maximal tangent stresses on the strength passport?
13. Give the definition of a ‘liquid strength passport’.
14. Make a passport of rock strength.
15. What are the conditions under which rock shear starts?

Laboratory work # 3

Determining specific weight of rocks, volume weight of rocks, and their porosity

1. Objective is to get knowledge of the methods to determine specific weight and volume weight as well as rock density and porosity during their independent determination using a technique of hydrostatic weighing, and with the help of a pycnometer.

Hydrostatic weighing is weighing in water.

Pycnometer is a constant volume measuring flask.

1.2. To determine application area of using the above mentioned parameters in mining.

2. General information

Density, porosity, specific weight, and volume weight are the fundamental characteristics of rocks used while calculating mining output, rock disintegration, excavation, preparation, transportation, mineral storing, and many other calculations.

The density indicator is also included in the calculation formulas to calculate the velocities of longitudinal and transverse waves while determining the acoustic and elastic parameters of rocks.

Density (ρ) is the mass of the hard rock phase m contained in a unit of volume $V_{hard\ rock}$:

$$\rho = \frac{m}{V_{hard\ rock}}, \ g/cm^3,\ k\ /m^3,\ t/m^3 \tag{3.1}$$

where $V_{hard\ rock}$ is the analyzed sample volume where pores and cavities are taken into consideration.

Specific weight ($\gamma_{specific\ weight}$) is the weight of the mineral matrix of the rock contained in a unit of volume $V_{mineral\ matrix}$:

$$\gamma_{specific\,weight} = \frac{P}{V_{mineral\,matrix}} \tag{3.2}$$

where P is the weight of the analyzed rock sample; $V_{mineral\ matrix}$ is the total volume of minerals making up the rock (without consideration of volume of pores and cavities between minerals).

Volume weight ($\gamma_{volume\ weight}$) is the weight of dry rock in its natural state, which is contained in the unit of volume $V_{hard\ rock}$:

$$\gamma_{volume\,weight} = \frac{P}{V_{hard\ rock}}. \tag{3.3}$$

The unit of mass contained in the volume unit has been taken as a unit of the values of specific weight $\gamma_{volume\ weight}$ and volume weight $\gamma_{volume\ weight}$, as parameters, stipulated by a gravitational field strength. ρ density and volume weight $\rho_{volume\,weight}$ are calculated for estimating the amount of substance.

When determining ***density*** as the main system measurement unit, the fact that a body mass always remains constant regardless of its location is taken into account, when weight and the specific weight of the body, can change quite significantly along with changesinthe weight***g***acceleration.

Volume weight is a unit mass of a dry rock volume in its natural state without structural disturbance (in terms of the given porosity) with g/cm^3, kg/m^3, and t/m^3 dimension.

The specific weight of the rock and its density are related by the ratio

$$\gamma_{specific\,weight} = \rho \cdot g, \tag{3.4}$$

where ***g*** = 9.81 m/c^2 is free fall acceleration.

Porosity (n) is the relative volume of pores and cavities per volume unit or the amount of free space per volume unit. There are total n_{total} porosity, and effective $n_{effective}$ porosity.

Effective porosity is the relative volume of open pores through which solutions and gases circulate.

Total porosity is the relative volume of all pores being available in the rock volume unit.

The total porosity can be determined if one knows specific rock weight, and volume rock weight:

$$n_{total} = \frac{\gamma_{specific\,weight} - \gamma_{volume\,weight}}{\gamma_{specific\,weight}} \cdot 100\%. \tag{3.5}$$

Direct measurement and hydrostatic weighing are the most popular techniques intended to analyze rock density.

Measurement is applied when the samples are of a regular geometric shape. The mass of the dry sample is determined by weighing after drying it at a temperature not higher than 105 ^{0}C for/during 24 hours. The density is calculated with 0.02 g/cm^{3}accuracy.

Hydrostatic weighing is used for the samples of any shape. To do this, the samples are polished to remove irregularities, after that they are dried to a constant weight, and then are weighed wet in the air; they are weighed finally using a hydrostatic method in a glass vessel with a liquid the sample is saturated. The calculation is carried out using the formula:

$$\rho = \frac{m_{dry}}{m_{saturated} - \left(m_{liquid} - m_{wire}\right)} \cdot \left(Q \cdot t - \lambda\right), \tag{3.6}$$

where $\boldsymbol{m_{dry}}$ is the dry sample weight, g; $\boldsymbol{m_{saturated}}$ is the saturated sample weight, g; $\boldsymbol{m_{liquid}}$ is the sample weight in a liquid, g; $\boldsymbol{m_{wire}}$ is the weight of wire used for hydrostatic weighing, g; $(Q \cdot t - \lambda)$ is temperature difference correction, and weighing in air correction. In terms of standard room temperatures (i.e. 18-22^{0}C), the correction is 0.997.

In the process of determination of both volume and specific weight using hydrostatic weighing method, the rock samples must be covered with paraffin (if they absorb moisture) to avoid changes in the natural volume of the sample and its weight. In this case, amount of the paraffin and its weight, are calculated by weighing the sample before paraffining and after it.

While mining, separation and fragmentation of rock result in their disintegration followed by changes in volume. Such rock characteristic is taken into consideration by means of a disintegration coefficient:

$$K_d = \frac{V_{distr}}{V_{undistr}}, \tag{3.7}$$

where $\boldsymbol{V_{distr}}$, $\boldsymbol{V_{undistr}}$ – disturbed and undisturbed amounts of the material.

Generally, the disintegration coefficient is more than one. It varies from 1.5 to 2.5 for coal and rock.

3. Facilities and materials

1. The rock sample under analysis (the sample is paraffin zed).
2. Crushed powder of the studied rock sample under analysis.
3. Pycnometer.
4. Counter balance
5. Glass vessel for water for hydrostatic weighing.

4. Procedure

The rock samples have already been paraffinzed to prevent moisture absorption while their submerging (to simplify calculations, the laboratory work does not involve volume and weight of the paraffin). The weighing results are recorded in Table 3.1; and all calculations with indication of dimensions are recorded in a copybook.

4.1. Determining volume weight using hydrostatic weighing method

4.1.1. First, ***m_1*** weight of the paraffinzed sample in the air is calculated by weighing it on the counter balance with 0.01 g accuracy.

4.1.2. Water-filled glass vessel is mounted on a stand. Using a thread, the sample is suspended to the balance-beam (Fig. 3.1) in a manner preventing from its contact with the vessel. After that, the sample is weighed in water to determine its weight ***m_2***.

The first weighing identifies the sample weight in the air ***m_1***; and the second one identifies he submerged sample weight ***m_2***.

The decreased sample weighting water depends upon a buoyant force; it is equal to the liquid weight forced out by the sample (Archimedes' law).

The sample amount is calculated by the formula:

$$V_{sample}=\frac{m_1-m_2}{\rho_{liquid}}. \qquad (3.8)$$

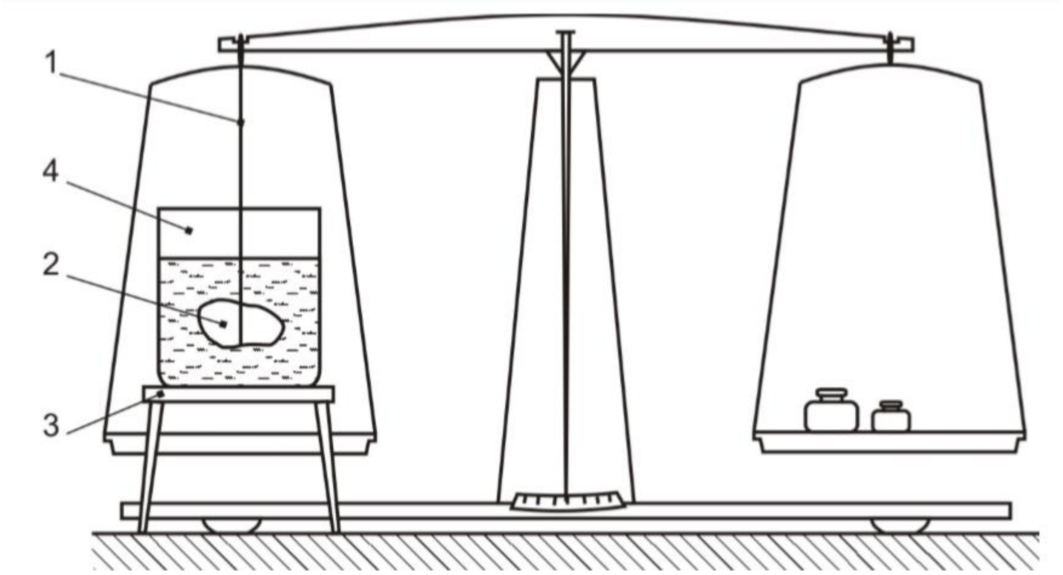

Fig. 3.1. Device for rock sample weighing in water:
1-thread; 2-rock sample; 3-stand; and 4-water-filledvessel

Approximately, the water density is equal to volume weight being 1g/cm^3. Thus:

$$V_{sample}=m_1-m_2. \qquad (3.9)$$

Using the hydrostatic weighing method, the volume weight is calculated by the formula:

$$\gamma_{volume\,weight}=\frac{m_1}{V_{sample}}, \text{ g/cm}^3. \qquad (3.10)$$

4.2. Determining the specific weight using a pycnometer

4.2.1. The dry pycnometer weight m_3 is identified with up to 0.01 g accuracy.

4.2.2. The crushed powder of the rock under analysis is weighed and the results are recorded in Table. 3.1. – powder weight is m_4.

The laboratory work applies up to 15-20 g of sand simulating the rock crushed to the powder state.

Then the crushed powder is stored on paper.

4.2.3. The pycnometer is filled with distilled water up to the mark, being guided by the lower meniscus; then its outer surface is wiped dry using filter paper and $m_5$weightis calculated.

4.2.4. After that, approximately half of the water from the pycnometer is poured and the crushed powder is filled in, which weight has been determined by a paragraph 4.2.2.

To remove air bubbles from the powder, it is necessary to mix it thoroughly by shaking the pycnometer.

4.2.5. The water is added into the pycnometer up to the mark (preferably with a pipette) and the pycnometer filled with water and rock powder is weighed for m_6 weight determination.

The water weight decreased down to the amount being equal to the product of the specific water weight γ_{water} per volume displaced by the powder (mineral matrix) $V_{specific\ weight}$.

Thus, taking into consideration that γ_{water} = 1 g/cm^3, the formula

$$V_{specific weight} = m_4 + m_5 - m_6. \tag{3.11}$$

Allows calculating accurately the volume of the powder mineral matrix.

4.2.6. Taking into consideration (3.2), (3.11) formulas, we obtain:

$$\gamma_{specific weight} = \frac{m_4}{m_4 + m_5 - m_6}. \tag{3.12}$$

4.3. Determining total porosity

The total porosity of the rock under analysis is identified by the formula (3.5).

The results of laboratory tests are recorded in Table. 3.1

Table 3.1

The results of the rock amount and specific weight calculation

The sample weight in air m_1, g	The sample weight in water m_2, g	The sample amount V_{sample}, cm^3	Volume weight, $\gamma_{volume\ weight}$, g/cm^3	The dry pycnometer weight, m_3, g	Weight of the powder (mineral matrix of the sample), m_4, g	Weight of the pycnometer with water m_5, g	Weight of the pycnometer with water and powder m_6, g	Specific weight, $\gamma_{specific\ weight}$, g/cm^3

Pay attention!
Transferring values of volume weight g/cm^{3}to other dimension:
1) to kg/m^3: $g \times 10^{-3}/cm^3 \times 10^{-6} = 1/10^{-3} = 10^3$ kg/m^3;
2) to t/m^3: $g \times 10^{-6}/cm^3 \times 10^{-6} = 1$ t/m^3.

5. Test questions for Laboratory work # 3

1. List density characteristics of rocks.
2. Why is it necessary to know density characteristics of rocks?
3. What is specific weight of rocks?
4. What is volume weight of rocks?
5. Which weight is more, volumetric or specific? Why?
6. What are porosity types?
7. What is total porosity?
8. What is effective porosity?
9. Define the Archimedes law and give an example of its use in this Laboratory work.
10. What is the idea of hydrostatic weighing method using pycnometer?

Laboratory Work # 4

Determining acoustic and elastic parameters of rocks by means of ultrasound

1. Objective is to get acquainted with one of the tendencies of using ultrasound in mining. Ultrasound is widely used in mining industry as the means to study the physical and chemical characteristics of rocks and formation; moreover, it controls and intensifies certain technological processes. The laboratory work applies the ultra-sound method (i.e. method of sounding) to determine acoustic and elastic parameters of rocks using UKB-1 device.

The method idea is to measure time of elastic oscillation spreading within a rock sample; to calculate their velocities and to determine the Young's modulus, the modulus of shearing, and specific wave resistance using the dependencies from the theory of elasticity.

Acoustic and elastic parameters of rocks characterize rock mass state within the bottom-hole space of mine workings; their changes are used to predict the risk of sudden rock and coal outburst; they are included in the formula of rock pressure calculation during the selection of support; they are also used to evaluate the ash content of coal etc.

2. General information

Elastic characteristics of rocks are evaluated by ***Young's modulus, shear modulus, Poisson's ratio, all-round compression modulus, elastic limit*** etc.

Coefficient of proportionality, being elastic rock parameter, corresponds to each type of the applied stresses (i.e. compression, tension, shearing) as well as to the deformations caused by them. Thus, the coefficient of proportionality between normal stresses (either compressive or tensile ones) σ and relative longitudinal deformation $\varepsilon = \frac{\Delta l}{l}$ corresponding to it, is ***modulus of elasticity1*** or ***Young's modulus***:

$$E = \frac{\sigma}{\varepsilon}. \tag{4.1}$$

The coefficient of proportionality between tangent stress τ and the corresponding deformation of shearδ is the shear modulus G:

$$\tau = G \cdot \delta. \tag{4.2}$$

Young's modulus and shear modulus are among the basic elastic parameters; they characterize rocks behavior in the context of a simple stress state. If volume stress state takes place then stress-relative volume change ratio is expressed by the ***all-***

round compression modulus K which can be calculated when ***E*** and ***G*** values are known:

$$K = \frac{E \cdot G}{3(G - E)}. \tag{4.3}$$

In practice, ***Poisson's coefficient /ratio-μ,*** being the coefficient of proportionality between the deformations –relative longitudinal $\Delta l/l$ and relative transverse $\Delta d/d$ – is often used.

All the ***three elastic parameters*** are connected by the equation:

$$\mu = \frac{E - 2G}{2G}. \tag{4.4}$$

For rocks, the ***μ***value is within 0.2-0.4 range being dimensionless value.

The basic elastic parameters of rocks also involve:

- wave propagation velocity;
- specific wave resistance; and
- absorption coefficient.

Longitudinal, ***transversal*** and ***surface*** waves appear under the effect of deformations within solid infinite media.

Longitudinal waves results from compression-tension deformation propagation. Since all substances have elastic resistance to volume compression, the ***longitudinal waves propagate within various environments: solid bodies, gases, liquids.***

Propagation velocity of a longitudinal elastic wave with in the absolutely unlimited solid isotropic environment is calculated by the formula:

$$C_p = \sqrt{\frac{E}{\rho} \cdot \frac{1 - \mu}{(1 + \mu) \cdot (1 - 2\mu)}}, \text{ м/с} \tag{4.5}$$

where ***E*** is Young's modulus, Pa, ***ρ*** is the rock density, g/cm^3; and ***μ*** is the Poison's coefficient.

Transversal waves result from shear deformation progress. Since shear resistance is not available in liquids and gases, the ***transversal waves propagate within solid bodies*** only.

Both ***longitudinal and transversal waves*** spread throughout the body volume and therefore are called volume ones.

Surface waves appear on the ‘solid body – vacuum ‘border. The surface waves propagate slower than longitudinal and transverse ones.

Specific wave rock resistance is calculated by the formula:

$$Z = \rho \cdot C_p. \tag{4.6}$$

Absorption coefficient is always greater in those rocks where oscillation rate is less than 1/m.

3. Facilities

1. UKB-1 device.
2. Counterbalance.
3. Calliper.

4. Procedure

1. Get two samples of rocks from the teacher.

2. Make measurements of the samples taking into consideration their shapes after the measurements have been made with up to the millimeter accuracy.

3. Weigh up the samples using the counterbalance with up to gram accuracy; determine volume density of each sample:

$$\rho = \frac{m}{V}, \tag{4.7}$$

where ***m*** is the sample weight, g; and ***V*** is the sample volume, cm^3.

4. Actuate the UKB-1 device and warm it up during 5-10 minutes until a token sound appears.

5. Press the rock sample between the UKB-1 sensors; then determine the time of ultrasound transmission under the supervision of the teacher (the values of the device readings will be expressed by microseconds (μs); $1 \mu s = 10^{-6}$ s).

6. Calculate propagation velocity of elastic oscillations for each sample:

$$C_p = l/t \text{, m/c} \tag{4.8}$$

where ***l*** is the size of sample side, along which measurements are made; ***t*** is the time of ultra sound trans mission being calculated as an average value of 3-4 dimensions in terms of one sample).

7. Determine the Young'smodulus by (4.5) formula, $\mu = 0.25$.

8. Calculate the shear modulus ***G*** by (4.4) formula.

$$\mu = \frac{E - 2G}{2G} \tag{4.9}$$

9. Calculate the module of all-round compression ***K*** by the formula:

$$K = \frac{E \cdot G}{3(G - E)} = \frac{E}{3(1 - 2\mu)}. \tag{4.10}$$

10. Determine the specific wave resistance ***Z*** by (4.6) formula.

Calculations are performed in a copybook; the final results are recorded in Table. 4.1.

Table 4.1

Sample	Rock	Sample size, cm	Sample volume, cm^3	Weight, g	Volume density, g / cm^3	Time, s	Propagation velocity of elastic oscillations, $\boldsymbol{C_p}$, m/s	Young's modulus, ***E***, kg / cm^2	Shear modulus, ***G***, g / cm^2	All-round compression modulus ***K***, g/cm^2	Specific wave impedance **Z**, g/cm^2

5. Test questions for Laboratory work # 4

1. Give a definition of elasticity modulus of type 1 (Young's modulus), and a formula for its calculation.
2. Give a definition of a shear modulus, and a formula for its calculation.
3. Give a definition of Poisson's coefficient, and a formula for its calculation.
4.Can transversal waves propagate in gases and liquids? Why?
5. What is characterized by the acoustic and elastic parameters of rocks?
6. What are the basic parameters evaluating the elastic characteristics of rocks?
7. List the main acoustic parameters of rocks.
8. What is the elastic limit?
9. Give a definition of elasticity modulus of type 2.
10. Give a definition of all-round compression modulus, and a formula for its calculation.
11. Give a formula to calculate propagation velocity of an elastic longitudinal wave.
12. What are surface waves? What are their typical media?
13. What are elastic waves?

Laboratory Work 5
Determining Young's modulus and Poisson's coefficient while testing rocks on uniaxial compression

1. Objective is to determine the elastic parameters of rocks (E and μ) with the help of static method using a DM-12 pressure strain gauge.

2. General information

Elastic characteristics are ability of rocks to restore their original shape and sizes after removing the load (stress). Proper proportionality coefficient between stresses and elastic deformations, being an elastic parameter, is available for each type of the applied stresses.

The proportionality coefficient between the acting normal stress σ (compressive or tensile one) and the corresponding relative longitudinal deformation $\varepsilon = \frac{\Delta l}{l}$ is the elasticity modulus (Young's modulus) ***E***:

$$\sigma = E\varepsilon \qquad (3.1)$$

The proportionality coefficient between tangent stress τ and corresponding deformation of shift δ is the shift modulus ***G***:

$$\tau = G\delta . \qquad (3.2)$$

The proportionality coefficient between relative longitudinal deformation $\frac{\Delta l}{l}$ and relative transverse deformation $\frac{\Delta d}{d}$ is the Poisson's coefficient:

$$\frac{\Delta d}{d} = \mu \frac{\Delta l}{l} . \qquad (3.3)$$

In the context of isotropic rocks, ***E***, ***G***, and μare interdependent as follows

$$\mu = \frac{\mathrm{E} - 2G}{2G} . \qquad (3.4)$$

The elastic rock properties, determined statically, characterize rock behavior in the context of relatively long-term process of its loading while compressing, stretching, and bending; in turn, dynamic rock properties characterize the rock behavior under transient influence (i.e. explosion, percussive drilling etc.)

Static determination of elasticity parameters is connected with careful and rather accurate measurements of a rock sample deformation while compressing, stretching, and bending. Either clock-type indicators with 0.001-0.002 mm graduation for measuring small deformations, the indicators of clock type division or electric strain sensors of resistance are used.

The determination of elastic parameters using the static method is connected with careful and rather exact measurements of a rock sample deformation under pressure/compression, stretching and bending.

To measure small deformations, the indicators of clock type with 0.001-0.002 mm graduation or electric resistance tensiometers are used.

The electric resistance tensiometers with B=5, 10, 15,20,40,60 mm base are a high resistance wire with 0.003 mm diameter shaped as a spiral (Fig.3.1).

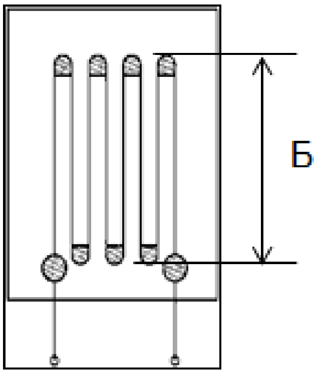

Fig. 3.1. Electric tensiometers

The measurements of longitudinal and transverse deformations of cylindrical rock samples under uniaxial compression are performed using DM-12 pressure tensiometer. The wire tension sensors are glued up to the rubber inserts of the tensiometer, which are pressed against the surface of the tested rock sample using springs and screws (Fig. 3.2).

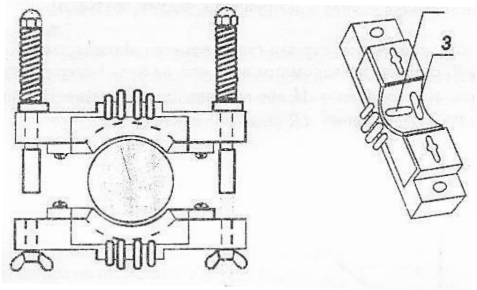

Fig.3.2. DM-12 pressure tensiometer: a is a general view; b is a plate of the pressure tensiometer; 1is a rock sample; 2 is a tension sensor to measure longitudinal deformation; 3is a tension sensor to measure transverse deformation

Pressure tensiometers of the type allow measuring material deformations with uniaxial compressive strength within the range from 100 to 3000x10^5 Pa.

The output wires of the tensiometers are connected to ID-1 device (strain gage), which is based on “Whitson Bridge” principle (Fig. 3.3).

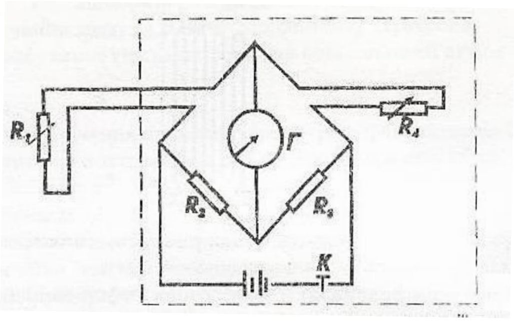

Fig. 3.3. Schematic diagram of ID-1 type tension station

The ID-1 device has an autonomous power supply, the power button K, and highly sensitive galvanometer ***G; R2, R3, R4*** supports are complexation ones, ***R1*** is the strain gauge resistance.

Before testing, the tensiometer is connected to the device. If ***R1=R2=R3=R4*** equality is observed, then the bridge balance is observed; galvanometer pointer is at zero. Under loading the sample to which the strain sensor is pressed tightly, the reduction and thickening of the sample shape changes the resistance of the load cell.

The bridge becomes unbalanced and the galvanometer pointer is deflected. Compensatory resistance*R4*nulls the galvanometer pointer and $\Delta \boldsymbol{R}$ increase is obtained depending upon $\Delta \boldsymbol{l}$ decrease or $\Delta \boldsymbol{d}$ sample thickening. Using the calibrated graph (Fig. 3.4), the obtained $\Delta \boldsymbol{R}$ helps determining $\Delta \boldsymbol{l}$ or $\Delta \boldsymbol{d}$:

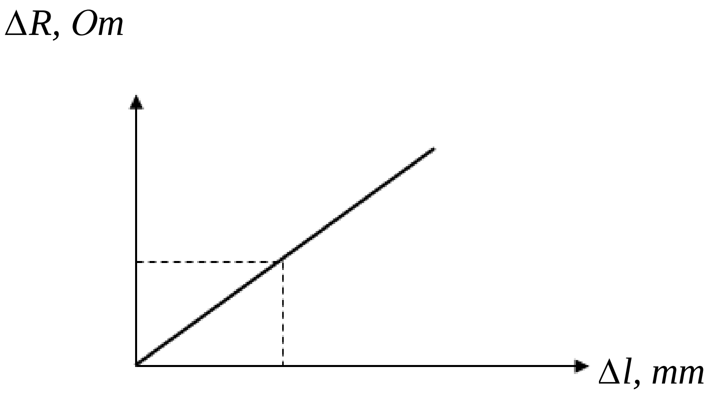

Fig. 3.4. Calibrated graph

For the materials (rocks) falling under Hooke's law, the elasticity modulus is determined by the formula

$$E = \frac{(P_n - P_{n-1})l}{F(\Delta L_n - \Delta l_{n-1})} 10^{10}\, Па, \qquad (3.5)$$

where P_n, and Δl_n are ultimate load and ultimate deformation of load interval, kg respectively; P_{n-1}, and Δl_{n-1} are initial load and initial deformation of load interval, kg respectively; l is the length within which deformation is measured, cm (tension sensor base); and F –cross-sectional area of the sample, cm^2.

The load on the sample should not exceed 50 % $\sigma_{outmost}$, kg.

3. Facilities

1. Pressure tensiometer DM-12.
2. Hydraulic press with pressure gauge.
1. 3. Example (strain station) ID-1.
4. Calliper.

4. Procedure

4.1. The rock samples, which height is within h_0=(1.3-2.5)*d_0, are provided by the teacher.

4.2. The plates of the pressure tensiometers are fixed on the sample installed in the center of the base plate of the press.

4.3. The output ends of the tensiometers are connected to the strain station.

4.4. The strain station is switched on and the galvanometer pointer is set to zero by R_4 resistance.

4.5. The oil valve of the press cylinder is closed; the pump lever increases the pressure. The equal loading intervals on the sample are set by the teacher.

4.6. When the target load of interval one is achieved, the galvanometer pointer is set to zero; then ΔR is used to determine Δl. The data are recorded in the table.

4.7. Sensor switching determines Δd as specified in paragraph 4.6. The obtained data are recorded in the table.

4.8. Similar determinations are performed when reaching the final loading of the second, third and other load intervals.

4.9. E, μ and G are determined for each loading interval; the obtained data and used to calculate E_{cp}, μ_{cp}, and G_{cp}.

4.10. The tests are terminated after obtaining the same E, μ and G values during following two loading intervals.

Table 3.1

The dimensions of the test sample, mm	Measurement base	Load, H	Changes in strain sensors resistance		Deformation in load intervals, mm	Elastic characteristics in load intervals
			Longitudinal	Transverse		

5. Test questions for Laboratory work # 5

1. What are the rocks characteristics stipulated by variousstress-deformation ratios?
2. What is stress?
3. What are stress types?
4. Determine the elastic parameters using a static method.
5. what is a mode procedure of using DM-12 pressure tensiometer.

Calculation tasks

Task # 1.

123 trolleys (cars) of coal have been extracted from a longwall during a shift. Disturbance ratio is 2. Volume weight of the coal is 1.4 g/cm^3. The trolley (car) capacity is 2 m^3. How much coal has been extracted during the shift?

Task # 2.

Thickness of a coal seam, being mined, is 1.4 m. The longwall stope advance is 0.7 m per shift. What is the number of cars to transport the shift output? Longwall length is 170 m. Theca type is VG-2.5. Disturbance ratio is 1.8.

Task # 3.

Thickness of a coal seam, being mined, is 1.3 m. The longwall stope advance is 0.7 m per shift. Longwall length is 190 m. Theca type is VG-2.5. Disturbance ratio is 1.8. Volume coal weight is 1.57 g/cm^3. Determine tonnage of coal mined per the shift.

Task # 4

Determine the volume of the broken rock mass in a quarry, if bench height is 14 m, its length is 70 m, and its width is 24 m. Disturbance ratio 1.8.

Task # 5.

Determine the volume of the broken rock mass in a quarry and the number of dump trucks for its transportation, if bench height is 14 m, its length is 60 m, and its width is 22 m. Capacity of each dump truck is 12 m^3.

Task # 6.

Determine the rock porosity, if its specific gravity is 2.3 t/m^3, and the volume weight - 1.85 t/m^3.

Task # 7.

Determine the area required for the finished product warehouse while a mine constructing if it should contain 10 thousand tons of coal. The coal specific gravity is 1.35 g/cm^3, K_d=2.0. The natural slope angle φ is 30°. Coal storage is in the open area in the form of a truncated pyramid. $\boldsymbol{H_{pyramid}}$=17 m.

Task # 8.

Determine the area required for the finished product warehouse while a mine constructing if it should contain 12 thousand tons of coal. The specific gravity of coal is 1.40 t/cm^3, K_d =2.0. The angle of natural slopeφ is 32°. Coal is stored in the open cone site.

Task # 9.

Determine the propagation velocity of longitudinal waves within an infinite solid isotropic environment (rock) (C_p), if

- Young's modulus (E) is 1.2×109 Pa;
- rock density is 1.4 g / cm^3;
- Poisson's coefficient (μ) is 0.38.

[C_p]=m/s.

Task # 10.

970 coal tons have been extracted from a longwall per shift. Disturbance ratio is 1.8. The coal volume weight is 1.5 g / cm^3. The trolley (car) capacity is 2.5 m^3. How many trolleys are needed to transport the coal mined?

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APPENDIXA

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REPORT
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Dnipro
2020

Educational edition

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PHYSICS OF ROCKS AND PROCESSES

METHODICAL RECOMMENDATIONS TO PERFORM LABORATORY AND PRACTICAL TASKS ON “PHYSICS OF ROCKS” SUBJECT FOR STUDENTS OF 184 MINING SPECIALISM AREA

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Published
at the National Technical University
“Dnipro Polytechnic”.
Certificate of entry into state register of DC No. 1842 dated 11.06.2004.
49005, Dnipro, D. Yavornytsky Ave., 19.