Methodology. To study the distribution of different types of rocks on the area under research the statistical analysis of the petrophysical characteristics of specific lithological formations of Precambrian crystalline basement was done. Petrodensity and petromagmatic groups of rocks based on the regularities of the relations between physical properties, composition and texture of the rocks were argued.

Findings. Analysis of new and archival actual material, and previous laboratory tests on determination of the physical properties of rocks allowed combining them into homogeneous groups according to the lithological and petrographic characteristics and taking into account their lateral extension. We distinguished thirty-six homogeneous groups of rocks and supplied them with histograms of density and magnetic susceptibility. The summarizing of the results of studies of the rocks within Kryvbass territory shows that the rocks belong to two general groups presented by granite-migmatite and sedimentary-metamorphic complexes.

Originality. The general populations of qualitatively homogeneous groups according to their lithological and petrographic characteristics and areal extent were composed.

Practical value. Detailed knowledge of the physical parameters of rocks allows charting various deep geological and ecological heterogeneities from the surface of the earth by geophysical fields and use the gravitational and magnetic fields, together with seismic and electrical exploration for the simulation of deep structure of Krivorozhsko-Kremenchugskiy, Tarapakovskiy, Saksaghanskiy and Vostochnyi faults.

Keywords: *Krivoy Rog basin, rocks, physical properties, density, magnetic susceptibility, group, geophysical fields*

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EXPERIMENTAL STUDY OF THE ABSORBTION EFFECT ON THE STRENGTH PROPERTIES OF SANDSTONE ROCKS

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ЕКСПЕРИМЕНТАЛЬНЕ ВИВЧЕННЯ ВПЛИВУАБСОРБЦІЇ НА МІЦНІСНІ ВЛАСТИВОСТІ ПОРІД ПІЩАНИКА

Purpose. The research aims to assess the effect of water absorption on the mechanical properties of sandstone rocks using a servo-controlled testing machine. This allowed investigating how the strength properties are affected by the changing content of absorbed water like this occurs on the site.

Methodology. The stress-strain curves were obtained from the uniaxial compressive strength by using a servo-controlled testing machine. Young's modulus and the brittleness index were measured for specimens prepared from a single block of sandstone. The specimens were divided into three groups prepared for testing under different conditions of absorption equilibrium.

Findings. The experimental results testified that there is a general tendency for both the uniaxial compressive strength and Young's modulus to decrease because of increasing absorption water content. It was established that the trend is not clear with the brittleness index and it is not possible from these data to see whether the index is unaffected by absorbed water content or has a maximum at some intermediate absorbed water content. The obtained results showed that Young's modulus and the brittleness index of the studied sandstone are not significantly affected by absorption over the range from air dry to saturation. However, the effect of absorption content on uniaxial compressive strength is just significant, the strength of the sandstone decreases by increasing absorbed water content.

Originality. This methodology has been applied for the first time to the conditions of Hassi Messaoud site. So, all the obtained results can be considered original. It allows identifying correctly the physical and mechanical parameters of soils influencing the site stability.

Practical value. The obtained results can help us to understand the effect of water absorption on rock mechanical properties of the studied site. They are also highly important for mechanical modelling of hydraulic fractures while drilling, borehole stability, reservoirs compaction, and subsidence analysis.

Keywords: *absorption, mechanical properties, uniaxial compressive strength, Young's modulus, brittleness index*

Introduction. Estimation of rock mechanical properties is considered among the most important components in any engineering project. In this regard, one of the most commonly used and fundamental mechanical parameter is uniaxial compressive strength (UCS) Brunoet et al. [1]; Minaeian and Ahangari [2].

Both for excavation and stability problems, knowledge of ground properties is essential so that excavation and stability system can be matched to the ground Bhasim et al. [3].

The uniaxial compressive strength is one of the most widely used for these properties and the purpose of this research was to study the variation in the compressive strength and the correlation of sandstone strength with other properties. Aqueous pore fluids exert significant mechanical and chemical effects on the rock. Previous studies have shown that the brittle strength of a rock is generally reduced in the presence of water, Yang et al. [4]. The water-weakening effect may arise from two mechanisms. The mechanical role of pressurized pore fluid tends to weaken rocks, and the chemical influence of pore fluids is to further weaken the rock through a reduction of surface free energy Paterson, subcritical cracking mechanism such as stress corrosion Atkinson and Meredith, or both combined.

Using a servo-controlled testing machine, complete stress-strain curves were obtained for specimens. Because specimen failure was controlled, brittleness of the sandstone could be studied from the form of the stress-strain relation after the peak load had been reached. Specimen preparation and the testing technique are described and stress-strain results are presented.

The strength and Young modulus, brittleness values are then correlated with absorption contents.

Site and sample details. A large, intact block of sandstone was obtained from the Hassi Messaoud site investigation which is situated 850 kilometres of Algiers. In terms of lithology, the rock is grey, medium-grained, weakly cemented sandstone. A sample of the rock was disaggregated by gentle pressure with a pestle and mortar, taking care not to crush individual grains, and the particle size distribution and the particle specific gravity were determined. It was found that 85 per cents of the particles fell in the medium sand range (0.2–0.6 mm) and ten per cents in the fine sand range (0.06–0.2 mm) and that the particle specific gravity was 2.66.

Experimental procedure. ***Specimen Preparation and Testing.*** The representative cores for use in the experimental work are obtained from block sample. Coring of the block samples was accomplished by diamond core drills. The original core of 95 mm was plugged with a diamond cores drill having 38 mm as nominal diameter. All core samples were cut to length/diameter ratio of 2.5:1. The ends of cores were ground flat and parallel (see fig.1). The diameter and length of each specimen were measured with a vernier to the nearest 0.01 mm.

The specimen were divided into three groups, one group was saturated by using a vacuum–saturation process, similar to that suggested by the U.S. Bureau of reclamation, this process consists of:

1. Oven-drying the specimen for a period of 24 hours at 105°C.
2. Placing the specimen in a bell jar under a vacuum exceeding for 24 hours.
3. Immersing the specimen in water while continuing with vacuum for another 24 hours.
4. Removing the vacuum and exporting the water containing the immersed specimen to the atmosphere for at least 48 hours.

This procedure eliminates air from rock pores and de–airs the water, atmospheric pressure. Then drives water into the rock, thus assuming saturation response completion of the 5-day cycle, the specimen is removed from the water surface dried, and then weighed .the absorption content is computed. The second group of specimens was immersed into water. The third group was allowed to air dry conditions because the oven-drying may sometimes cause erratic changes in the physical property. The mass of each specimen was determined immediately before testing, and the absorption content immediately after.

Fig. 1. Cylindrical sandstone specimen

The affixing to the specimens of two axially oriented foil strain gauge type (N22-FA-5-120-H). These pairs are placed diametrically opposite each other and located centrally on the specimen. During testing the pairs are connected up with pairs of gauges. On-dummy sample away from the machine to give temperature variation compensation. This whetstone bridge is formed and strain changes are monitored by changes in the voltage across the bridge. The testing procedure was essentially the same as that described by (Hudson and Morgan) and the following account, slightly modified, is taken from their report. The compression tests were carried out in a fart-response, closed-loop, programmable testing machine (fig.2). This type of machine was used because a constant displacement rate can be achieved throughout the test i.e. failure is controlled after the maximum load bearing capacity of the specimen has been reached; and because it is programmable and automatic. The closed-loop, servo-control principle is shown in fig.3. A feedback signal (f) representing the actual condition of an experimental variable, in this case the axial displacement, is continually compared with a program signal (p) representing the required experimental condition. The feedback signal corresponding to the displacement between the specimen ends was generated by four displacements transducers located at 90 degree intervals around the specimen. The individual transducer outputs were summed to provide a voltage equivalent to the average specimen displacement. This feedback signal was compared with the program signal produced by a function generator. The program signal increased linearly with tune enabling a constant displacement or strain rate to be achieved. An error signal (e) occurred if there was any difference between the feedback and program signals; this activated a servo-valve causing the hydraulic pressure in the loading ram to be adjusted and the error signal to be reduced. Feedback and program signals were frequently compared and high speed adjustments made so that the experimental condition followed the programmed condition. The control mechanism and advantages are explained further by (Hudson, Crouch and Fairhurst [4]. To carry out a test, the specimen was inserted in the testing machine between platens having the same diameter as the specimen. The program was switched on. The specimen was then displaced at a constant rate of 2x10–3 mm/sec, corresponding to an axial strain rate of about 3x10–3 per cent/sec. Displacement was thus the independent variable and force was the dependent variable. Failure was then controlled beyond the peak force because the displacement was programmed to increase at a constant rate regardless of whether this necessitated a rise or fall in applied force. The load was monitored with a pressure transducer and a complete force-displacement curve obtained for each specimen on an X–Y recorder. Axial load was additionally monitored by a remote X–Y chart recorder, which was used to monitor the axial displacement detected by the strain.

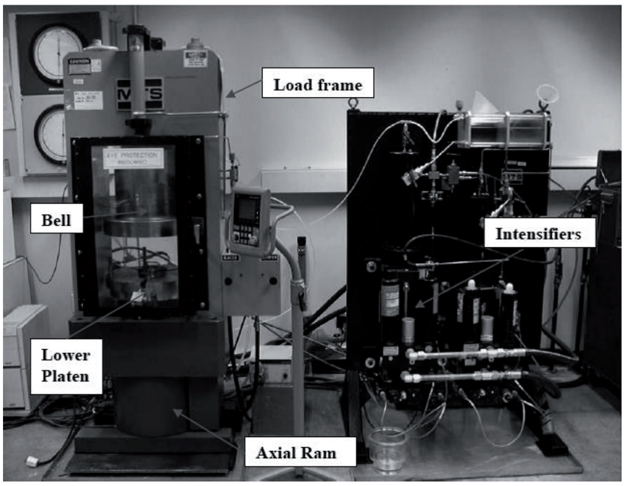

Fig. 2. Machine with tests servo controlled on the test sample

Results. Load displacement curves obtained from the X–Y recorder were converted to stress-strain curves by dividing the load by the original cross- sectional area of the specimen to give stress and by dividing the displacement by the original length of the specimen to give strain; a typical result is shown in fig.3. The brittleness index (*B*) defined by Hudson and Morgan as

$$B = AE / (AE + Ap),$$

where *AE* is the area beneath the stress-strain curve before the peak stress and *Ap* is the area beneath the stress-strain curve after the peak stress (fig.4) was obtained for each curve by Tamaya Digital Planimeter measurements. The value of *B* can range from 0 to 1, for perfectly brittle rock with a post-failure curve descending vertically, *B* is unity since *Ap* is zero; for perfectly ductile rock with a horizontal post-failure curve, *Ap* is infinite and *B* becomes zero.

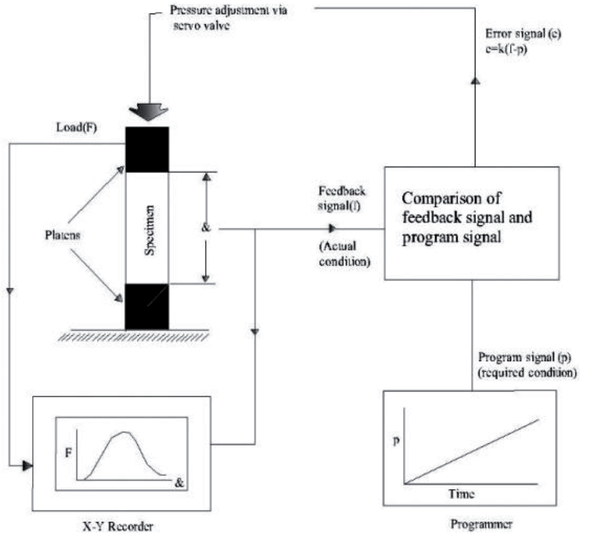

Fig. 3. Closed–loop programmable testing machine control system

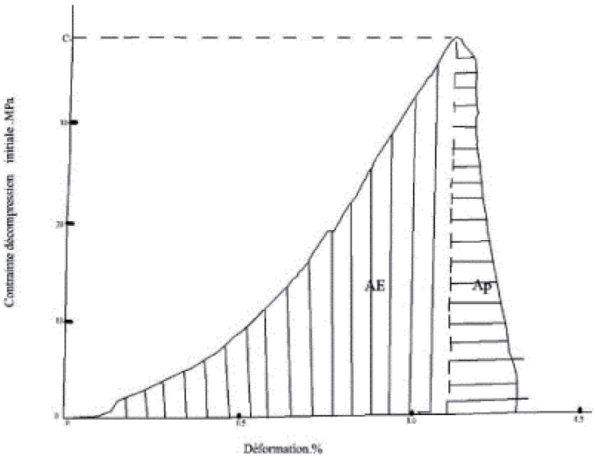

Fig. 4. The stress-strain curve after the peak stress was obtained for each curve by Tamaya Digital Planimeter measurements

The uniaxial compressive strength (Co) was obtained from the peak of each curve. Young's modulus (E) and Poisson's (μ) was obtained from the stress-strain curve (fig. 5, 6). Young's modulus and Poisson's ratio are determined from the stress strain relationships for each stage. Young's modulus is equal to the ratio of axial stress to axial strain. Poisson's ratio is equal to the ratio of lateral strain to axial strain. As shown in fig. 5, the Young's modulus is calculated from the slope of the straight-line portion of the stress-axial strain curve. Poisson's ratio can be calculated using the average slope of the straight-line portion of the stress-radial strain curve and the average slope of the axial curve. The values of Young's modulus and Poisson's ratio are calculated from the stress-strain curve at 50% of the failure or maximum load. Fig. 6 shows the methodology of determining Poisson's ratio.

Summarised in table. To study the effect of absorption content on the strength properties, individual values of uniaxial compressive strength, young's modules and brittleness index have been plotted against individual values of absorption content for each specimen in fig. 7, 8, 9.

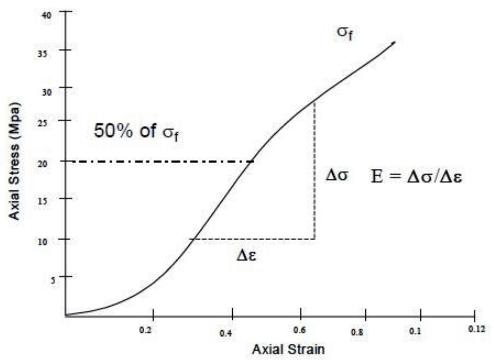

Fig. 5. Calculation of Young's Modulus at 50 % of peak strength

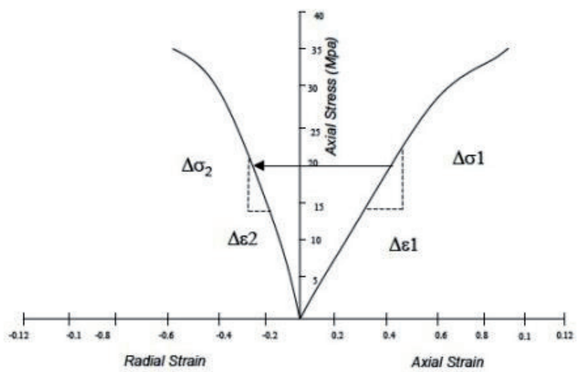

Fig. 6. Calculation of Poisson's ratio from stress-strain data: σ_f – axial stress; $\Delta\varepsilon_2$ – radial strain; $\Delta\varepsilon_1$ – axial strain; E – Young modulus

Discussion and Conclusion. Fig. 7–9 show the effect of absorption content on the uniaxial compressive strength, Young's modulus and brittleness index of the sandstone respectively. There is a general tendency for both the uniaxial compressive strength and Young's modulus to decrease with increasing absorption content. With the brittleness index the trend is not clear and it is not possible from these data to see whether the index is unaffected by absorption content or has a maximum at some intermediate absorption content. In each of the figures, a least square regression line for the data is shown together with the value of the computed correlation coefficient (r). A value of $r^2 \geq 0.6$ has been considered in rock mechanics as indicating a reasonable correlation. Judged by this criterion, fig. 8 and 9 shows that Young's modulus and brittleness index of the sandstone are not significantly affected by absorption changes over the range from air dry to saturation. Fig. 7 However, shows that the effect of absorption content on uniaxial compressive strength is just significant, the strength of the sandstone decreasing with increasing absorption content. The mean uniaxial compressive strength of the air-dry sandstone 37 MN/m^2 (table), is almost identical with that of the dry chalk marl studied by Hudson and Morgan [6]. However, while the mean strength of the saturated Sandstone had fallen to 23 MN/m^2 that of the saturated chalk marl had fallen to 2 MN/m^2, showing a very different response to increasing absorption content. The mean Young's modulus of the Sandstone varied from 7.2 GN/m^2 for air-dried rock to 5.5 GN/m^2 for saturated rock (table). Even the lower of these values is higher than the maximum value of 3 GN/m^2 reported for the chalk and shows the sandstone is the stiffer of the two rocks. The mean brittleness index of the Sandstone varied from 0.61 to 0.77 (table). These values are lower than the values of 0.83 to 0.85 reported for the chalk and, shows the sandstone is the less brittle of the two rocks when judged by the criterion of brittleness index.

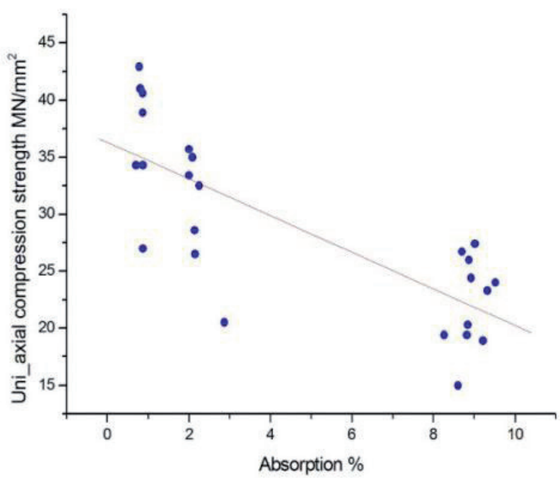

Fig.7. Effect of absorption on uniaxial compressive strength

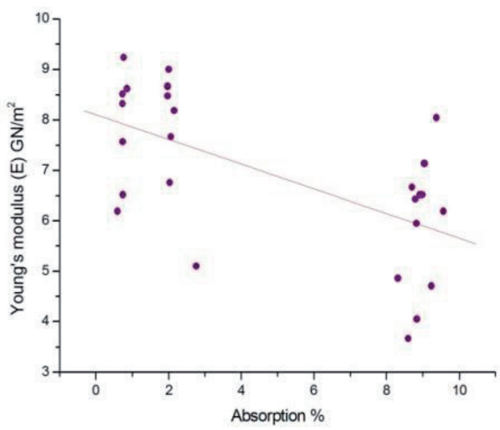

Fig. 8. Effect of absorption content on young's modulus

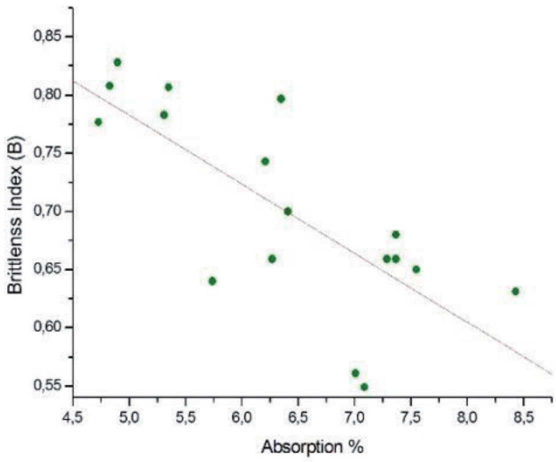

Fig. 9. Effect of absorption content on the brittleness index

Table

Mechanical property test results

Statistical characteristics properities	Number of specimens	State	Mean	Standard deviation
Uniaxial compressive strenghth (C_0), Mpa	30	Dried	36.78	2.64
	30	Immersed in water	30.01	3.78
	30	Saturated	29.68	4.73
Young's moudulus (E) Gpa	15	Dried	16.42	2
Poisson's ratio	15	Dried	0.25	0.05
Brittleness index (B)	15	Dried	0.65	0.09
	15	Saturated	0.68	0.08
Absorption (%)	20	Remaining 2	0.02	0.08
	20	Immersed in water	4.57	0.82
	15	Saturated	6.90	0.55
Unit weight, g/cm^3	30	Dried	2.19	0.045

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Мета. Дослідження направлене на оцінку дії ефекту поглинання води на механічні властивості порід песчаника з використанням сервокерованої випробувальної машини. Це дасть можливість показати, як змінюються міцнісні властивості при зміні вмісту поглиненої води, подібно до того, як це відбуваються в натурних умовах.

Методика. Криві „напруги-деформації" отримані з використанням сервокерованої випробувальної машини шляхом udновісного стискування. Модуль Юнга, а також показник чутливості ґрунту, були виміряні для зразків, виготовлених з одного блоку піщанику. Зразки були розділені на три групи, підготовлені для випробувань у різних умовах рівноважного поглинання.

Результати. Експериментальні результати свідчать, що існує загальна тенденція як для одноосьової міцності на стискування, так і модуля Юнга до зменшення зі збільшенням вмісту поглиненої води. Було встановлено, що дана тенденція не зовсім визначена для показника чутливості ґрунту. За наявними даними неможливо встановити, чи залежить цей показник від вмісту поглиненої води або він має максимум при деякому проміжному вмісті. Отримані результати показують, що модуль Юнга і показник чутливості ґрунту трохи змінюються при поглинанні в діапазоні від сухого стану до стану насичення. Проте, вплив поглинання на міцність при одновісному стискуванні є відчутним, міцність піщаника зменшується зі збільшенням кількості поглиненої води.

Наукова новизна. Ця методика застосована вперше на ділянці Хасси Мессауд. Тому всі отримані результати можуть вважатися оригінальними. Вона дозволяє коректно визначити всі фізичні та механічні властивості ґрунтів, що впливають на стійкість ділянки.

Практична значимість. Уперш за все, отриманні результати можуть допомогти в розумінні впливу ефекту поглинання води на механічні властивості порід на ділянці, що вивчається. По-друге, вони особливо важливі для механічного моделювання тріщин гідророзриву при бурінні, стійкості свердловин, ущільнення колекторів і аналізу просадження ґрунтів.

Ключові слова: *поглинання, механічні властивості, міцність при одновісному стискуванні, модуль Юнга, показник чутливості ґрунту*

Цель. Исследование направлено на оценку действия эффекта поглощения воды на механические свойства пород песчаника с использованием сервоуправляемой испытательной машины. Это даст возможность показать, как изменяются прочностные свойства при изме-

нении содержания поглощенной воды, подобно тому, как это происходят в натурных условиях.

Методика. Кривые „напряжения-деформации“ были получены с использованием сервоуправляемой испытательной машины путём одноосного сжатия. Модуль Юнга, а также показатель чувствительности грунта, были измерены для образцов, изготовленных из одного блока песчаника. Образцы были разделены на три группы, подготовленные для испытаний в различных условиях равновесного поглощения.

Результаты. Экспериментальные результаты свидетельствуют, что существует общая тенденция как для одноосевой прочности на сжатие, так и модуля Юнга к уменьшению с увеличением содержания поглощенной воды. Было установлено, что данная тенденция не совсем определённая для показателя чувствительности грунта. По имеющимся данным невозможно установить, зависит ли этот показатель от содержания поглощенной воды или он имеет максимум при некотором промежуточном содержании. Полученные результаты показывают, что модуль Юнга и показатель чувсытвительности грунта незначительно изменяются при поглощении в диапазоне от сухого состояния до состояния насыщения. Тем не менее, влияние поглощения на прочность при одноосном сжатии является ощутимым, прочность песчаника уменьшается с увеличением количества поглощенной воды.

Научная новизна. Эта методика применена впервые на участке Хасси Мессауд. Поэтому все полученные результаты могут считаться оригинальными. Она позволяет корректно определить все физические и механические свойства грунтов, влияющие на устойчивость участка.

Практическая значимость. Прежде всего, полученные результаты могут помочь в понимании влияния эффекта поглощения воды на механические свойства пород на изучаемом участке. Во-вторых, они особенно важны для механического моделирования трещин гидроразрыва при бурении, устойчивости скважин, уплотнения коллекторов и анализа просадок грунта.

Ключевые слова*: поглощение, механические свойства, прочность при одноосном сжатии, модуль Юнга, показатель чувствительности грунта*

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