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DROPLET METHOD FOR INVESTIGATING THE CAPILLARY–POROUS STRUCTURE OF MATERIALS

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Abstract. A simple express methodology is proposed for the non-destructive characterization of the capillary–porous structure of building materials, based on monitoring the spreading dynamics of a colored droplet applied to the surface of a specimen. The method relies on recording the temporal evolution of the stain and interpreting the resulting $R^2(t)$ dependence within the Lucas–Washburn framework and porous-media theory. This enables, in a single experiment, the evaluation of effective porosity, capillary conductance, permeability, mean effective pore radius, effective diffusion coefficient, as well as wetting parameters (contact angle, surface tension) and indicators of deviation from the ideal capillary regime. The experimental procedure consists of video recording the spreading of a droplet of aqueous dye solution (e.g., methylene-blue), followed by frame extraction and computer processing of the stain contours. From the stain area, an equivalent radius is obtained, the $R^2(t)$ relationship is constructed, and its slope is used to extract integral capillary characteristics of the material. The approach provides high informational value at minimal equipment cost, making it suitable for field applications and preliminary screening of restoration zones. Using shell limestone as an example, it is demonstrated that the method allows quantitative identification of structural variations even within a single block or layer-an essential requirement for selecting compatible primers and restoration mortars with controlled rheological and adhesive properties. A consistent data-processing workflow is outlined: linearization of the $R^2(t)$ dependence, determination of capillary conductance, evaluation of effective porosity from the absorbed liquid volume, and reconstruction of permeability and contact angle values based on known liquid parameters. Verification criteria for assessing the plausibility of the obtained values are presented, including penetration depth and typical ranges of permeability and mean pore radii for cemented carbonate rocks. The proposed methodology effectively complements diagnostic approaches already used in restoration practice and provides a parametric basis for selecting mixtures adapted to the real geometry of the substrate’s capillary–porous network. Thus, the developed droplet-based analysis toolkit combines operational simplicity with the ability to obtain key structural characteristics required for scientifically grounded design of repair and restoration solutions for shell limestone e heritage objects.

Keywords: capillary–porous structure, droplet spreading, Lucas–Washburn method, shell limestone, restoration materials.

Introduction. Assessing the capillary–porous structure of calcite-containing rocks, particularly shell limestone, is essential for the justified selection of restoration and plaster compositions. Adhesion, deformation and filtration compatibility, water absorption, vapor permeability, and the overall durability of the "substrate–coating" system are directly governed by the geometry and connectivity of the pore space. For shell limestone, this is especially critical due to the high structural heterogeneity even within one layer and the sensitivity of the surface to local variations in microrelief, which makes it difficult to ensure reliable contact of the restoration material with the base and requires taking into account the individual characteristics of the restoration areas. That is why modern approaches insist on a preliminary physico-chemical analysis of the surface and adjustment of the composition according to operational properties in compliance with the requirements of authenticity and compatibility, which for shell limestone objects acquires the status of a mandatory technological stage.

The express method proposed in the work is based on the registration of the time evolution of a stained liquid spot that spreads along a capillary–porous network near the surface of the sample. The method is attractive because it combines experimental simplicity with high informational value: video recording of the process and elementary computer processing of the contours are enough to obtain a set of integral parameters of the porous medium from the $R^2(t)$ curve. In practice, a methylene-blue solution was used. The video was split into frames, the spot area and geometric parameters were measured, circularity was evaluated, and the relevant physical quantities were computed – all without damaging the sample, with minimal equipment requirements, and with the possibility of performing the procedure directly on the object. Such a ratio of "simplicity of measurement – significance of results" is especially attractive for monument conservation work, where full-scale laboratory methods are often impractical or impossible at all.

Here it is appropriate to briefly review the theoretical principles of the method. Under the condition of dominance of capillary forces, the spread of a drop in the approximation of an isotropic pore network obeys the Lucas–Washburn law, which leads to a linear of $R^2(t)$ on time. It should be noted that real samples of shell limestone are rarely isotropic. The presence of internal boundaries of division, microcracks and zones of inhomogeneous cementation locally changes the paths of liquid filtration, leading to deviations from the ideal Lucas–Washburn capillary regime. Such effects are manifested in the form of a change in the slope of the $R^2(t)$ dependence at certain time intervals or in the appearance of weak anisotropy of the spot. However, for small drop volumes and dominance of wetting over gravity, these deviations do not violate the overall linearity, and therefore can be taken into account as part of the effective parameters φ_{eff} and K_c. The slope of this dependence is interpreted as the capillary conductance coefficient K_c (hereinafter denoted A), which in combination with known fluid parameters (dynamic viscosity μ and surface tension γ) and hydrophilic-hydrophobic surface properties (contact angle θ) allows us to reconstruct the structural characteristics of the material. When the absorbed volume $V(t)$ or sample thickness is known, the method yields the effective porosity φ_{eff}. From the capillary pressure or front velocity, the effective pore radius reff can be estimated. With reference values of γ, μ and θ, the intrinsic permeability k can also be derived. The set of these quantities forms a "passport" of the porous medium, in which A, φ_{eff}, k, r_{eff}, θ, D_{eff}, are mutually consistent and allow us to control the plausibility of the estimates for the spot geometry, penetration depth, and ranges typical of cemented carbonate rocks.

The practical relevance of the measured characteristics for the selection of restoration and plaster compositions lies in the direct connection between the parameters of the pore network of the base and the formulation solutions. Knowing φ_{eff} and k, the permissible intervals of water consumption, wetting and drying rates are established and the structure of the binder matrix (lime/cement ratio, proportion of microfillers) is selected to ensure compatibility in terms of filtration capacity and avoid excessive capillary suction, which provokes salt migration. The parameter r_{eff} focuses on the granulometry of the aggregate and microfillers: the particle distribution should "hook" the dominant pore channels for reliable mechanical fixation without clogging the vapor paths. The wetting angle θ and the associated wetting energy control the choice of hydrophilic-hydrophobic modifiers and primers, which allows balancing adhesion and capillary water absorption and reducing the risk of formation of efflorescence defects. The D_{eff} estimate helps predict the kinetics of moisture and dissolved salt transport in the base–layer system, setting maintenance regimes and operational constraints. In conclusion, the described approach provides a parametric basis for adapting the composition to a specific shell limestone surface, which is consistent with modern practice in material selection for historical sites and complements other methods of surface structural analysis.

Unlike more complex methods that require specialized microscopy and separate laboratory measurements of hydrophobicity and texture parameters, the express drop approach allows you to quickly obtain a consistent set of target values directly on the site, and the obtained parameter intervals for limestone and shell limestone serve as additional verification of the realistic estimates and the basis for making design decisions. Such a balance of simplicity of the procedure and the significance of the results corresponds to the task of scientifically based selection of restoration and plaster systems for objects made of shell limestone.

Analysis of literature sources. Capillary wetting and imbibition in porous building materials – from classical equations to express methods based on the "dye drop" – remain one of the most informative approaches for non-destructive diagnostics and selection of restoration and plaster compositions. In modern works, the general dynamics of the front is described by the Lucas–Washburn law, which leads to a linear dependence of $R^2(t)$ on time under the dominance of capillary forces. Deviations from Lucas–Washburn are associated with inertial effects, gravity, wettability, angle hysteresis and multimode pore distribution [1–5]. For thick porous substrates, analytical solutions are consistent with observations of a drop that simultaneously spreads and infiltrates, and corrections to Lucas-Washburn scaling are proposed [3]. In parallel, two-phase models based on filtration/porous media equations (Richards/LBM/PNM) generalize Lucas–Washburn to cases of partial saturation and complex pore geometry [2, 4, 6]. Against this background, "field" protocols (RILEM II.4, ASTM C1585) provide standardized capillary indices (capillary absorption coefficient, drying index) and are widely used in stone conservation to assess the effectiveness of water repellents and salt resistance [7–12].

The express approach with fixation of the spread of a colored drop directly implements the Lucas–Washburn framework: from the slope $R^2(t)$ the combined coefficient of capillary conductance K_c is extracted, and with a known volume of absorbed liquid $V(t)$ the effective porosity φ_{eff} is obtained; with additional data – to the permeability k, the effective pore radius r_{eff} (due to capillary pressure or the Kozeny–Carman correlation) and, sometimes, to θ [1–4]. The linearity of $R^2(t) \sim t$ is a diagnostic feature of the capillary regime and allows us to estimate K_c, φ_{eff} and r_{eff} for shell limestone. In practice, this is implemented through frame-by-frame analysis of the spreading methylene-blue drop, followed by measurement of the spot geometry, linear regression of the $R^2(t)$ on time, and subsequent substitution into the basic Lucas–Washburn and Kozeny–Carman relations.

Compared to laboratory methods (mercury porometry, N_2/BET adsorption, MRI/NMR relaxation, microCT), the "drop method" has the advantages of simplicity, low cost and sensitivity to surface changes, which is critical for assessing the compatibility of restoration systems with a porous base. However, classical standards also take into account limitations: locality of measurement, the influence of texture/anisotropy and surface preparation mode. Therefore, in conservation practice, it is advisable to combine it with RILEM/ASTM standards, which calibrate the absorption rate on representative scales and allow validating trends "before"/"after" treatments [7-12]. At the foundation level, generalized analyses show that Lucas–Washburn scaling works well in mesoporous/macroporous carbonates before the appearance of capillary competition and gravitational effects. Network and micromodel experiments quantify the validity and deviation domains [5, 6].

For carbonates of the shell limestone type, recent petrophysical studies highlight the wide variability of pore types/sizes and connectivity, which directly determines k, φ_{eff}, electrical conductivity and degradation behavior. Pore-permo correlations for shell limestone differ from those typical for microporous limestones and require local calibrations [2, 13]. For restoration practice, this means the need to select soil-plaster-finish systems that match the capillary conductance and the "breathability" of the substrate: too low K_c/φ of the composition relative to the substrate will contribute to the accumulation of salts/moisture at the interface and delamination; a consistent capillary profile reduces the risks of salt weathering [8, 10]. That is why it is advisable to use fast "drop" indices (slope $R^2(t)$, estimate K_c, φ_{eff}) as screening criteria when selecting compositions for more laborious test cycles (RILEM II.4, accelerated salt weathering) [7, 8, 10].

An important modern line is the convergence of "droplet hydrodynamics" with digital morphometry and fractal surface descriptors: fractal dimension (by box-counting, triangular prisms, power spectrum, variational method) correlates with roughness/texture and affects the effective wetting angle, initial spreading and local infiltration [14–17].

In applied works for shell limestone, it has been shown that fractal metrics provide a quantitative basis for assessing "geometric smoothing" after priming: the difference in fractal dimensions before/after treatment can serve as a criterion for selecting a composition taking into account adhesive-capillary compatibility [16].

The combination of express droplet kinetics with fractal analysis of surface images forms a complementary set of indicators for the prompt but well-founded selection of restoration and plaster systems for a specific shell limestone.

In general, the comparison of approaches shows the following: Lucas–Washburn/droplet techniques are the most accessible for capillary mass transfer screening and preliminary selection of compositions; RILEM/ASTM standards are necessary for validated quantitative assessment and comparison of "before/after" treatments. Fractal morphometry is a bridge between surface geometry and wetting hydrodynamics, which allows setting target parameters of "compatibility" of restorative materials with a specific porous substrate.

The purpose of the work is to develop and test an express method for determining the capillary–porous characteristics of shell limestone based on the dynamics of droplet spread, taking into account the influence of internal separation boundaries and microcracks, determine the conditions for the applicability of the Lucas–Washburn approximation, and obtain generalized (effective) parameters φ_{eff}, k, r_{eff}, suitable for scientifically substantiated selection of restoration and plaster compositions.

Materials and research methods. In the study, shell limestone was used as a model material, which is characterized by a pronounced capillary–porous structure and high heterogeneity of pore size distribution. Samples were taken from typical blocks used in the masonry of historical buildings, while the surfaces for research were previously cleaned of dirt and dust without additional grinding in order to preserve the natural relief. An aqueous solution of dye (methylene blue) was used as the working fluid, which provided a distinct contrast of the stain against the stone background and did not significantly change the physicochemical parameters of water (viscosity, surface tension).

The measurement method consisted of applying a drop of known volume (0.02–0.05 ml) to the sample surface using a micropipette. Further spreading and absorption of the liquid were recorded using a digital video camera in real time. The resulting video files were divided into frames, after which the contours of the spot were determined using software analysis. The equivalent radius $R(t)$ was calculated from the spot area, the dynamics of which were monitored throughout the experiment.

Research results. From the analysis of the dependence of the spot radius on time, several key properties of the capillary–porous structure can be identified. Below is a model proposal, according to the method of which each property is determined.

Based on the dependence of the radius $R(t)$ on time, it is possible to determine the effective porosity φ_{eff}, the capillary conductivity coefficient K_c, the average effective pore radius r_{eff}, the coefficient of diffusion of liquid in a porous medium D_{eff}, (wetting angle θ, surface tension γ, if not previously known, permeability of the material k, volumetric resistance to liquid movement, and the deviation index from the ideal capillary regime (if observed).

Some of the above parameters were determined in the course of studying shell limestone, which is the primary material forming and undergoing restoration in historic buildings. These values are very important for making informed choices about plaster and restoration compounds.

The dependence of the radius of a water or other solvent or colored solution spot on time is determined by the Lucas–Washburn model. If capillary forces dominate, then according to the Lucas–Washburn equation (1):

$$R^2(t) = \frac{\gamma \cos\theta}{2\mu} \cdot \frac{k}{\varphi_{\text{eff}}} \cdot t\,, \tag{1}$$

where $R(t)$ is the radius of the spot, γ is the surface tension, θ is the wetting angle, μ is the viscosity of the liquid, k is the permeability, φ_{eff} is the effective porosity.

From experimental data, the model allows determining the combined capillary conductivity coefficient (2):

$$K_c = \frac{\gamma \cos\theta}{2\mu} \cdot \frac{k}{\varphi_{\text{eff}}}\,. \tag{2}$$

It is extracted from linear regression using the experimental dependence $R^2 \sim t$. If the amount of absorbed liquid $V(t)$ is known, the method allows to proceed to the effective porosity (3):

$$\varphi_{\text{eff}} = \frac{V(t)}{\pi R^2(t)h}, \tag{3}$$

where h is the thickness of the material.

To determine the average pore radius, capillary pressure is used (4):

$$\Delta P = \frac{2\gamma\cos\theta}{r_{\text{eff}}}. \tag{4}$$

If pressure information is available, r_{eff} can be determined. The effective radius value can also be obtained by expressing it in terms of the front velocity using an adapted Lucas–Washburn model.

For capillary diffusion, an analogy with diffusion is sometimes used. The effective diffusion coefficient D_{eff} includes the parameters of capillary transport. Analysis of the $R^2(t)$ graph allows us to estimate D_{eff} (5):

$$R^2(t) \sim D_{\text{eff}}t. \tag{5}$$

If γ, μ, k and φ_{eff} are known, $\cos\theta$ can be expressed from the expression for K_c, and then the angle itself. This is relevant for porous materials when the contact angle can be directly determined by the absorption of liquid by the porous material.

The experimental dependencies obtained reflect the combined effect of microstructural factors – porosity, cracking and internal border section between grains. Within the proposed approximation, they are integrated into the concepts of "effective porosity" and "effective permeability". Thus, even in the presence of small cracks or porous areas of varying connectivity, the results are interpreted as averaged characteristics of the macroporous network. This ensures the accuracy of the method for evaluating real restoration materials and natural stones with complex structures.

Practical part. The practical implementation of the used methods was based on the processing of the drop image obtained by frame-by-frame video recording of the spread of a drop stained with methylene blue solution. Some frames of this video storyboard are given in Fig. 1.

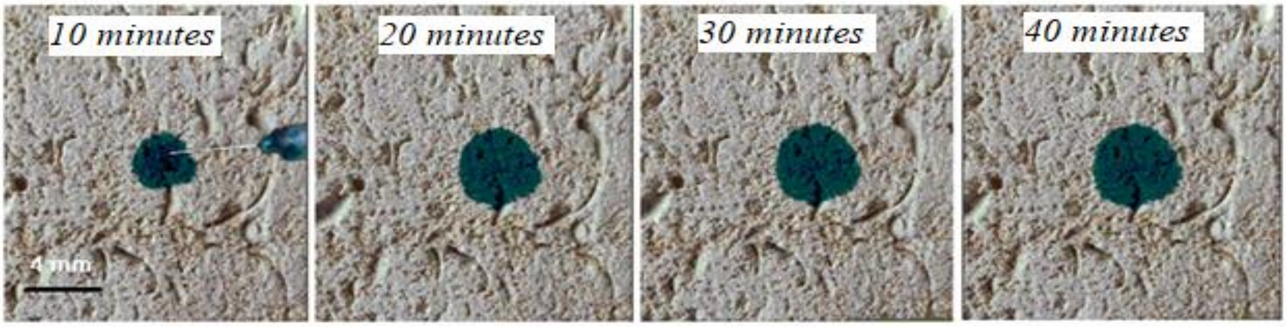

Fig. 1. The process of spreading a stain of a diluted solution of methylene blue on a sample of shell limestone

By analyzing these and other images using the Scion Image package, data on the shape and size of the spot were obtained, which are presented in Table 1.

Table 1 – Geometric characteristics of the size and shape of a liquid spot

No.	*Area*	*Perim*	*Major axes*	*Minor axes*	*Angle*	*Circle*	*AR*	*Round*
1	5.430	9.979	2.828	2.445	119.093	0.685	1.157	0.865
2	10.350	13.043	3.691	3.570	138.976	0.765	1.034	0.967
7	12.770	14.387	4.193	3.877	112.399	0.775	1.082	0.925
3	18.360	17.398	5.069	4.612	97.030	0.762	1.099	0.910
4	19.400	16.793	5.131	4.814	95.375	0.865	1.066	0.938
5	19.420	17.695	5.170	4.783	102.179	0.779	1.081	0.925
6	20.770	17.404	5.209	5.077	98.306	0.862	1.026	0.975

In Table 1 the following notations are used:

– *Area* – spot area, square millimeters;

– *Perim* – perimeter (length of the outer border of the spot);

– *Major axes* – major axis of the approximating ellipse (by length);

– *Minor axes* – minor axis of the approximating ellipse (in width);

– *Angle* – the angle between the main axis and the line parallel to the abscissa axis in the image;

– *Circ* – a measure of roundness. A value of 1.0 indicates that the circle will be perfect. The closer this value is to 0.0, the more elongated the resulting circle will be (6):

$$Circ = 4\pi \frac{(Area)}{(Perim)^2}, \tag{6}$$

– *AR* – measure of roundness. Ratio of axes of approximating ellipse (7):

$$AR = \frac{Major\ axes}{Minor\ axes}, \tag{7}$$

– *Round* – a measure of roundness, which is calculated by the formula (8):

$$Round = 4 \frac{(Area)}{\pi (Major\ axes)^2}. \tag{8}$$

A value of 1.0 indicates perfect roundness of the spot.

The values of the roundness measures in Table 1 indicate the adequacy of the assumption of roundness of the drop in the calculations. Therefore, to obtain the initial data (the square of the radius), the spot plane can be used, which was done.

The practical implementation of the considered methodology is carried out in the following sequence:

1. Plotting the graph of the dependence of R^2 on time. If the dependence is linear, then the system is controlled by capillary transport.

2. Determination of the slope coefficient $A = \frac{dR^2}{dt}$.

3. Calculate $K_c = A$.

4. Calculate φ_{eff} based on the volume of absorbed liquid.

5. Taking into account data on the physical properties of the liquid, the missing parameters φ_{eff}, θ, k, etc. are calculated from the model.

Graph of the dependence of R^2 on time (Fig. 2)

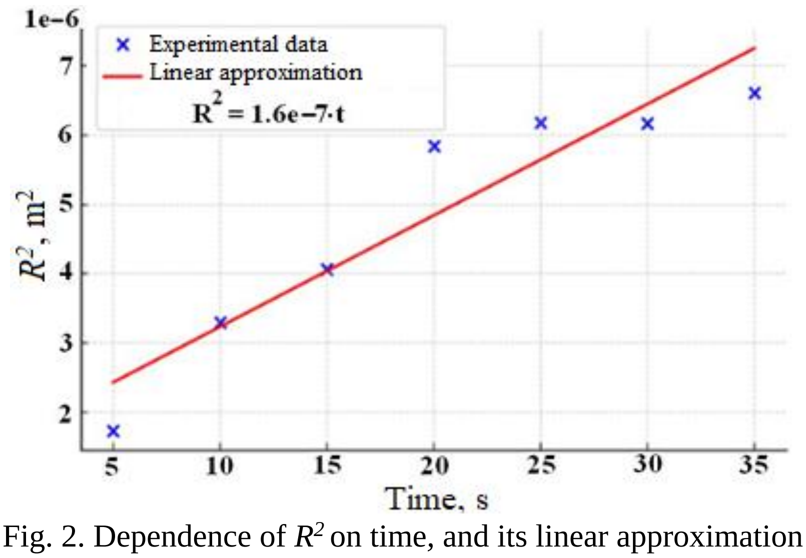

Fig. 2. Dependence of R^2 on time, and its linear approximation

The dependence of R^2 on time and its linear approximation shows that the spread of a spot in a porous material obeys the linear Lucas–Washburn law (9):

$$R^2(t) = A \cdot t\,, \tag{9}$$

where $A = 1.61 \cdot 10^{-7}$ m^2/s.

The Lucas–Washburn equation allows us to proceed to the calculation of structural characteristics. The basic formula for calculating structural properties (10):

$$A = \frac{\gamma \cos\theta}{2\mu} \cdot \frac{k}{\varphi_{\text{eff}}}. \tag{10}$$

Let us calculate it relatively according to the following relation (11):

$$\frac{k}{\varphi_{\text{eff}}} = \frac{2\mu A}{\gamma \cos\theta}, \tag{11}$$

where $A = 1.61 \cdot 10^{-7}$ m^2/s is found from the graph, $\mu = 1.0 \cdot 10^{-3}$ is the viscosity of water, $\gamma = 0.072$ N/m is the surface tension of water. The average wetting angle, according to the previous experiment, was $\bar{\theta} \sim 36°$, then $\cos(\bar{\theta}) \sim 0.8$. Substituting the values, we obtain (12):

$$\frac{k}{\varphi_{\text{eff}}} = \frac{2 \cdot 1.0 \cdot 10^{-3} \cdot 1.61 \cdot 10^{-7}}{0.072 \cdot 0.8} \approx 5.59 \cdot 10^{-9}\, m^2. \tag{12}$$

This relation $k/\phi_{\text{eff}} \approx 5.59 \cdot 10^{-9}\, m^2$ combines the permeability of the material *k*, m^2, and the effective porosity ϕ_{eff} (dimensionless volume fraction). If we assume $\phi_{\text{eff}} = 0.25$ (realistic for shell limestone), then (13):

$$k \approx \phi_{\text{eff}} \cdot \frac{k}{\phi_{\text{eff}}} = 0.25 \cdot 5.59 \cdot 10^{-9} = 1.40 \cdot 10^{-9}\, m^2. \tag{13}$$

For limestones and shell limestone, typical permeability values are shown in Table 2.

Table 2 – Typical permeability values for different materials

Material	Permeability k, m²
Fine sand	10^{-11} - 10^{-12}
Limestone	10^{-14} - 10^{-11}
Shell limestone	10^{-10} - 10^{-8}

The result obtained $k \approx 1.29 \cdot 10^{-9}\, m^2$. This is consistent with the range of porosity values of shell limestone, especially those that have been exposed to weathering or have natural cracks.

Let's check by the volume of the liquid. The volume of the solution $V = 0.02$ ml $= 2 \cdot 10^{-8}$ m^3 Maximum spread area (according to the last value): $S_{\max} = 20.77\ cm^2 = 2.077 \cdot 10^{-5}\, m^2$. Let's estimate the average penetration depth: $h = \frac{V}{S} = \frac{2 \cdot 10^{-8}}{2.077 \cdot 10^{-5}} \approx 0.96\ mm$. Penetration depth < 1 mm – plausible for tests with an aqueous solution on dense but porous limestone or shell limestone.

The assessment of the plausibility of the results for the shell limestone is summarized in Table 3.

Table 3 – Plausibility assessment of results for the shell limestone

Parameter	Value
Coefficient *A*	$1.61 \cdot 10^{-7}$ m^2/s
$\frac{k}{\phi_{\text{eff}}}$	$5.59 \cdot 10^{-9}$ m^2
Estimate k at $\phi_{\text{eff}} = 0.25$	$1.40 \cdot 10^{-9}$ m^2
Penetration depth assessment	~ 0.96 mm
Plausibility	High for a shell limestone

Estimate the average pore radius r_{eff} using the approximate formula – a consequence of the Kozeny–Carman equation (14):

$$k = \frac{r_{\text{eff}}^2}{8} \cdot \frac{\varphi_{\text{eff}}}{\tau} \quad \Rightarrow \quad r_{\text{eff}} = \sqrt{\frac{8k\tau}{\varphi_{\text{eff}}}} . \tag{14}$$

For different values of tortuosity typical for a shell limestone τ (Table 4):

Table 4 – Estimated average pore radius at different tortuosity values

Tortuosity τ	r_{eff}, mm
1.5	0.249
2.0	0.287
2.5	0.321

Thus, a pore radius of ~0.25–0.32 mm is a plausible estimate for cemented carbonate rocks such as shell limestone.

Estimate the pore density (number of pores per 1 m^2). For this we will use the relation (15):

$$N = \frac{\varphi_{\text{eff}}}{\pi r_{\text{eff}}^2} . \tag{15}$$

The results of calculations for three characteristic values of the pore radius are given in Table 5.

Table 5 – Pore density at different average radius values

Pore radius r_{eff}, mm	The number of pores per 1 m^2, pcs
0.249	1 284 900
0.287	963 700
0.321	770 940

The number of pores of about 1 million per square meter is quite typical for porous limestone and shell limestone. Let us make a general assessment of the plausibility of the obtained results (Table 6).

Table 6 – Assessment of the plausibility of the obtained values

Characteristic	Value	Plausibility for a shell limestone
Permeability k	$1.40 \cdot 10^{-9}$	High – within typical values
Pore radius r_{eff}	0.25 – 0.32 mm	Characteristic range
Penetration depth	~0.96 mm	Expected when saturated
Pore density	$0.7 – 1.3 \cdot 10^6$ pores/m^2	Realistic

Conclusions. Comparison of the results with data from literature sources indicates their adequacy to the typical characteristics of the materials under study. Given the influence of internal boundaries and microcracks, the method should be considered an effective approximation that is valid in cases where capillary forces prevail over gravitational forces and the filtration process is not accompanied by the opening or change in the geometry of cracks. Under such conditions, the parameters φ_{eff}, k, r_{eff} reflect the integral response of the porous medium and remain suitable for quantitative identification of the structure. However, since each sample of shell limestone has a unique pore structure, which is associated with different conditions of its origin and different nature of environmental influences, the study of the capillary–porous structure should be carried out for each restoration object separately. Thus, the goal of the work – verification of the suitability and limits of applicability of the drop method for real heterogeneous carbonate rocks – has been achieved. The results confirm the possibility of using effective parameters φ_{eff}, k, r_{eff} for parametric selection of restoration compositions. The simplicity and ease of implementation of the proposed method allow for easy application of the method directly in the conditions of restoration of a cultural heritage object.

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КРАПЕЛЬНИЙ МЕТОД ДОСЛІДЖЕННЯ КАПІЛЯРНО-ПОРИСТОЇ СТРУКТУРИ МАТЕРІАЛУ

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Анотація. Запропоновано просту експрес-методику неруйнівного аналізу капілярно-пористої структури будівельних матеріалів за динамікою розпливу краплі забарвленої рідини поблизу поверхні зразка. Метод ґрунтується на реєстрації часової еволюції плями та подальшій інтерпретації залежності $R^2(t)$ у рамках рівняння Лукаса–Вашбурна й підходів теорії пористих середовищ, що дає змогу з єдиного експерименту оцінити ефективну пористість, коефіцієнт капілярної провідності, проникність, середній ефективний радіус пор, ефективний коефіцієнт дифузії, а також параметри змочування (кут змочування, поверхневий натяг) і показники відхилення від ідеального капілярного режиму. Експериментальна реалізація базується на відеореєстрації розтікання краплі водного розчину барвника (зокрема метиленового синього) з подальшим кадруванням та комп'ютерною обробкою контурів плями; з площі плями визначається еквівалентний радіус, будується залежність $R^2(t)$, за нахилом якої одержують інтегральні капілярні характеристики матеріалу. Такий підхід забезпечує високу інформативність за мінімальних вимог до обладнання, придатний для польових випробувань і первинного сортування ділянок реставраційних робіт. На прикладі вапняку-черепашнику показано, що метод дозволяє кількісно ідентифікувати варіації структури навіть у межах одного шару або блока, що критично важливо для підбору сумісних ґрунтовок і реставраційних розчинів із заданими реологічними та адгезійними властивостями. Запропоновано послідовність оброблення даних: лінеаризація $R^2 - t$, оцінка капілярної провідності, перехід до ефективної пористості за об'ємом поглиненої рідини, відновлення проникності та кутів змочування з урахуванням відомих фізичних параметрів рідини; наведено критерії перевірки правдоподібності розрахунків (глибина проникнення, характерні діапазони проникності та середніх радіусів пор для цементованих карбонатних порід). Методика органічно доповнює прийняті в реставраційній практиці підходи попередньої діагностики поверхні та слугує основою для параметричного добору складів, адаптованих до реальної геометрії капілярно-пористої мережі субстрату. Таким чином, розвинений інструментарій аналізу розпливу краплі поєднує простоту виконання з можливістю отримання ключових структурних характеристик, необхідних для науково обґрунтованого проектування ремонтно-реставраційних рішень для об'єктів із вапняку-черепашнику.

Ключові слова: капілярно-пориста структура, розтікання краплі, метод Лукаса–Вашбурна, вапняк-черепашник, реставраційні матеріали.

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