Digital Photogrametry in Investigation of Application membranes on the Surfaces of Cementitious Materials

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Purpose The purpose of this work is to demonstrate usage of the photogrametry in construction, testing and monitoring of structures. **Method** The method of photogrametry is based on capturing digital shots of the cementitious surface covered with a membrane preventing water loss from concrete either by single shot or time-lapse method. By converting the pictures into gray scale and analyzing the brightness either of the whole surface or any differential area, we are able to calculate an evenness of the membrane application, a prediction of water loss from cementitious material, humidity underneath the membrane, and the areas of the structure most likely weakened due to excessive water loss. **Results & Discussion** We analyzed the effectiveness of concrete curing by application of a membrane (paraffin–based) on the surface of fresh concrete while studying loss of water depending on boundary conditions of the exposure to the ambient environment. The results in the picture help to refine the data and show this is a means of curing works up to 70%.

***Keywords**: automation, photogrametry, analysis, cementitious materials, water loss*

INTRODUCTION

Dealing with concrete and cement based materials in construction, for sustainability of production and durabilitiy (linked to expsenses), there exists a phenomenon of dependance of almost each performance on water content, expressed as water to cement ratio. There must not be neither too much nor too low water. This work is focused on practical application of the digital photogrametry in analysis of current state of concrete structures – mostly flat and exposed to severe boundary conditions.

Why water loss and what does affect?

As mentioned above, water loss determines process of hydration. To produce cocnrete of desired performances, there is some needed water content which must be provided. Its overrun leads to deterioration in quality. On the other hand, if there, in concrete, is too little water, hydration terminates and besides of that concrete undergoes undesired shrinkage what results in formation of cracks and this way shortening of durability due to ingress of harmfull gasses etc. Both cases are wrong. A general approach is to produce concrete with as so low water conctent as possible with respect to fresh concrete properties. Therefore, loss of water from these concretes is rather serious issue.

Prevention

In general, operations, techniques and deliberate actions aimed at prevention of loss of water from concrete are together called curing. That must not been emphasized that through the years there have been developed many, more or less effective and sofisticated, curing methods. One of those which during last couple of years achieved the biggest success in construction, especially civil engineering, is membrane curing. This method, preferably used for large flat concrete structures, such as pavements and bridge decks, is based on spraying of curing solution, curing emulsion or suspension on the surface of finished concrete structure as soon as possible to avoid evaporation of water to the ambient environment to which the concrete surface is exposed[5]. After some (short) time, thin coating loses water and starts to protect the concrete. Until recently, there has been almost no chance to monitor a thickness, effectiveness or uniformity of this protective film. There were simple methods based on weighing of reference application area and this way checking the uniformity of application and calculating the result membrane thickness. This way, however, just application settings or adjustments were performed and checked. An evaluation of the uniformity and effectiveness of the applied film on the particular structure lacked. Usage of hereinunder described method in daily construction praxis can ensure instant evaluation quality of applicacion of the membrane and help to minimize drying shrinkage of conscrete, eliminate the cracks formation and enhance the durability.

MEASUREMENT & AUTOMATION

Measurement involves common digital photogrametry technique. The concrete surface covered with liquid-applied curing membrane is photographed either once or continuously (depending on measurement purpose). From one shot (of certain surface area), there can be calculated an uniformity of the application or if you want uniformity of the membrane thickness (and relating actual efficiency). From continuous shooting, of course, the uniformity of thickness but also time-depending efficiency of curing and prediction of water loss from concrete surface, as well as local volume changes or local stress can be predicted. The investigated parameter is the brightness of the picture. A fundamental principle is that any material´s light-reflection properties depend on the the surface texture and moisture. Generally, wet materials look darker as reflect less percentage of incident light. Based on this knowledge and purpose of the liquid-applied curing membranes (minimize water evaporation from concrete), we can conclude that darker areas in the picture are better cured then those which seem lighter.

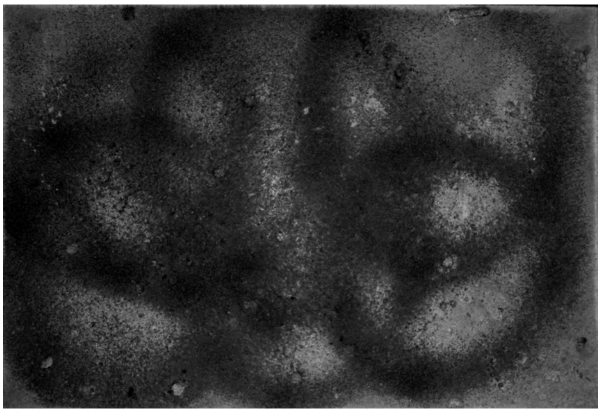

Fig.1. Example of the laboratory sample of concrete covered with sprayed membrane with visible pattern of application (after software adjustment)

Process of automation the measurement consists of cyclicly repeated operations of taking picture of the concrete surface in certain position, than moving the camere above adjacent position making a stripe across the structure and then moving forward in direction of main dimension of the structure and, of course, repeating of described sequence. Captured pictures should overlap somehow in both directions.

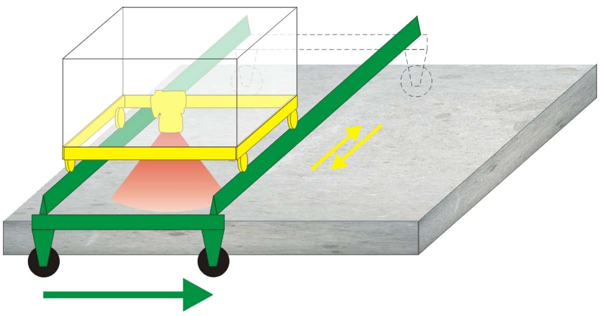

Fig.2. Scheme of a frame holding and operating a camera above the premature concrete structure

By programming a macro (e.g. for Image-Pro software) looking up for the identical spots (e.g. based on aggregate grains on the surface or some cavities) a user is able to automatically composite all the taken photos making an overall picture of certain area. It could be convenient to set this area to be predetermined by position of future contraction joints or so.

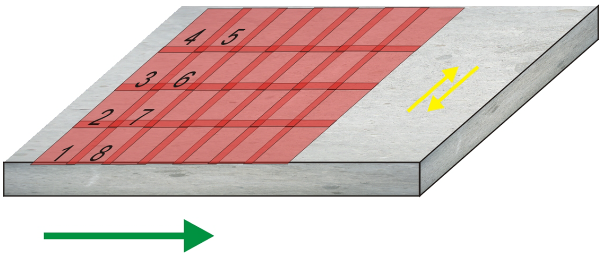

Fig.3. Scheme of taken pictures and overlapping areas

By gathering the acquired data directly in PC or lap top and using the evaluation principles (described hereinafter) a contractor can instantly analyze the efficiency of the membrane curing and if needed, make provisions against rapid water loss from concrete.

Very important is to properly schedule the test according to boundary conditions of the environment (ambient temperature, relative humidity, wind velocity and sun radiation) determining intensity of water evaporation from the surface. There must be sufficient contrast between spots with evidently sufficient membrane thickness and evidently insufficient. With rising contrast level the dynamic range rises along. That is a key parameter in sense of accuracy.

To achieve a higher level of accuracy, it is essential to take the pictures of the uniformly lit concrete surface. By lighting of the surface perpendicularly, the user may avoid distortion of the results by eventual shadows cast by some jogs.

It is recommended to expose in automatic or semiautomatic regimes (to medium - 18% grey) with matrix measurement. There are no requirements on maximum shutter speed, aperture and color management, however it is recommended to keep ISO sensitivity low as there is no relevant study on influence of the noise on the results.

Evaluation & Interpretation

The technique of evaluation of uniformity and/or efficiency of the liquid applied membrane is based on software adjustments of the shots and subsequent statistic analysis of the brightness channel.

As a first step, the composite picture has to be cropped off the edges (outside the structure). If the investigated surface declines somehow from the camera sensor there must be performed correction of the perspective.

Since just brightness channel is investigated and with respect to size of the composite files, it is recommended to convert to grey scale.

It is obvious that the pictures lack contrast (has got low dynamic range) as can be seen in upper stripe in fig. 4. Even due to perpendicular lighting and automatic exposure, there are neither deep shadows nor highlights. The figure 4, in its middle stripe, shows the dynamic range of the picture in regard to absolute values 0-255, whereas the zero represents no brightness and with value 255 the 100 % brightness is associated. From this picture it can be seen that actual dynamic range is just some fraction of absolute dynamic range.

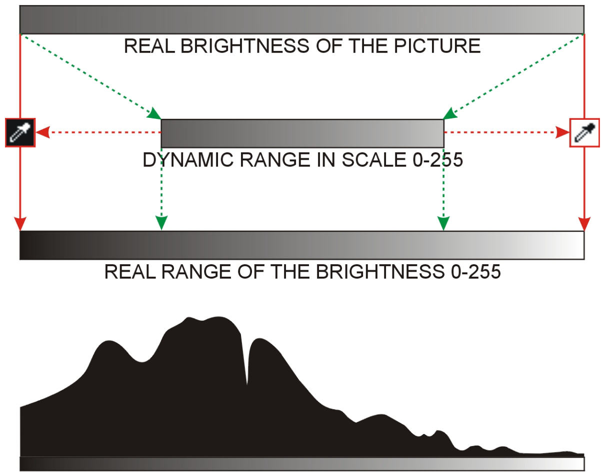

Fig.4. Principle of the dynamic ranges and their adjustments

The figure 4 is prepared in a way, where the darkest (75 %) grey correspond to absolute value 64 and the brightest (25 %) grey corresponds to absolute brightness of 191. If subtract these two values (191-64) we will get 127 what is approximately half of the available dynamic range. The half dynamic range would carry twice higher uncertainty within brightness analysis. In general, an increase in uncertainty equals to multiple of reciprocal of the ratio of dynamic range of the picture to absolute dynamic range. For precising of the analysis of the picture is essential to extend the dynamic range of the picture trying to meet the absolute dynamic range. In common softwares, it is possible using function "levels". In this step, there is assigned the zero value (0 % brightness) to the darkest spot in the picture.

The brightness of the individual pixels in initial dynamic range are now (in adjusted) picture transformed into brightness in manulally (or automatically) given range. The brightness analysis is further performed on adjusted picture.

The very first step in analysis itself is to determine a frequency of the pixels of single brightness level in range of 0-255, which is graphically presented as common histogram (e.g. fig. 4). Along a horizontal axis, the brightness is to be set from 0 to 255. The vertical axis shows the relative frequency of occurrence of pixels carrying given brightness information. The relative frequency $P(b_i)$ in (%) is to be determined automatically according to formula 1, where $p(b=b_i)$ (-) is a pixel carrying brightness information b which equals to searched brightness b_i, p_x is a number of pixels in x direction and p_y is a number of pixels in y direction.

$$P(b_i) = \frac{\sum_{i=0}^{255} p(b=b_i)}{p_x \cdot p_y} \cdot 100 \qquad (\%) \qquad (1)$$

The outcomes of the analysis are the statistic parameters of investigated data file (composite picture) to which the picture can be considered because during the exposure, there is assigned an individual value (from 0 to 255) of brightness to every single pixel according to efficiency of curing in that very spot. In this meaning the brightness is a stochastic variable. The main statistic parameter of the data file are an average value of the brightness b_{AVG} (-), standard deviation σ_b (-), file size = number of pixels and a number of the found brightness levels $\Sigma(b_i)$ (-). From the formula 2, there is to be derived the relative dynamic range DR_R (%) of the picture.

$$DR_R = \frac{\sum_{i=0}^{255} b_i}{255} \cdot 100 \qquad (\%) \qquad (2)$$

DR_R provides information on a resolution or uncertainty of the measurement. The information on an average brightness of the picture j, $b_{AVG,j}$ is given in scale 0-255 what is for obvious reasons impractical scale. Therefore, according to formula 3, it is transformed to an average brightness value $^{100}b_{AVG}$ given in (%) of grey scale. The same approach is to be applied, according to formula 4, to an average value of the standard deviation σ.

$$\overline{^{100}b_{AVG}} = \frac{\sum_{j=1}^{n} b_{AVG,j} \cdot \frac{100}{255}}{n} \qquad (\%) \qquad (3)$$

$$\overline{^{100}\sigma_b} = \frac{\sum_{j=1}^{n} \sigma_b \cdot \frac{100}{255}}{n} \qquad (\%) \qquad (4)$$

This way modified characteristics of the data file represent one sample (surface) exposed to ambient environment with certain combination of the boundary conditions. Coming out of display of the differential areas with absolute curing using membrane, i.e absolute black (100 % grey) and attempt to meet the absolute coverage of the sample (surface) with the (liquid applied) membrane, it is favourable to transpose the average brightness into an invert (formula 5). The average brightness is to be transposed to the invert parameter which characterizes the data file in a sense of achievement of the idealized absolute curing (100 %). It means, 100 % coverage of the surface with membrane and as a result – black (100 % grey) on 100 % of the surface.

$$\frac{1}{\overline{{}^{100}b_{AVG}}} = \frac{\sum_{j=1}^{n}\left(100-\left(b_{AVG,j}\cdot\frac{100}{255}\right)\right)}{n} \quad (\%) \qquad (5)$$

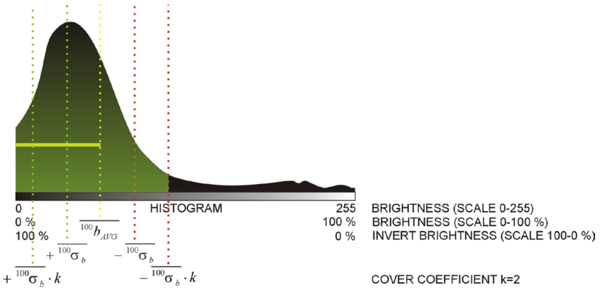

Fig.5. Principle of evaluation and interpretation of brightness histogram and statistical parameters of the data file

From now on just the individual samples (surfaces or their parts) are to be evaluated using the invert parameters. Then the average invert brightness of the sample may be understood as an average level of accomplishment the absolute curing or as an average level of the sample with absolute curing (by membrane). Therfore, if the average (invert) brightness ${}^{100}b_{AVG}$ meets e.g. 75 % and the standard deviation σ_b is 10 %, then sample was cured on 75 % of the surface. Hence, the statistical file is large enough (in multiple of 10^6 pixels) it is reasonable to deal with dispersion σ_b^2 or standard eviation σ_b of investigated brightness and therefore with the uniformity in thickness of applied membrane or process of application as such. For simplification, hereinafter just "uniformity of application" is being used. In terms of uniformity, the interesting areas are at the outer areas of the histogram. The left part was adjusted by defining a "black point". If there are not any clear frequencies of high brightness at the left part, then the application was quite uniform. Acquired data on the average brightness of the sample ${}^{100}b_{AVG}$ (%) and standard deviation ${}^{100}\sigma_b$ (%) are used for determination of enlarged uncertainty (or data reliability) by cover coefficient k. To a confidence probability 68,27 % corresponds k=1, to 95,45 % corresponds k=2 and to the confidence probability 99,73 % corresponds k=3. In fig. 5 and in common practice, it is sufficient to use k=2 by which it can be derived from formulas 6 and 7 an interval ${}^{100}b_L$ – ${}^{100}b_U$ (%). With the confidence probability 95 %, there belong either the average brightness or assigned average area with absolute curing, to this interval.

$${}^{100}b_L = \overline{{}^{100}b_{AVG}} - \left(k\cdot\overline{{}^{100}\sigma_b}\right) \quad (\%) \qquad (6)$$

$${}^{100}b_U = \overline{{}^{100}b_{AVG}} + \left(k\cdot\overline{{}^{100}\sigma_b}\right) \quad (\%) \qquad (7)$$

From the average brightness ${}^{100}b_{AVG}$ (%) and from standard deviation ${}^{100}\sigma_b$ (%) at selected level α=0,1 (i.e. reliability 1-α = 0,9) and number of datapoints m (multiple of 10^6), the 5 % fractile $Q_{0,05}$ of the brightness is derived following formula 9. The $Q_{0,05}$ equals to lower tolerance interval $b_{L,0,05}$ (%) which is defined as a subtraction of a degree of freedom $\chi_{0,05}$ from the invert average brightness ${}^{100}b_{AVG}$ (%). The degree of freedom is defined by formula 8 as a conjunction of factor of one-side tolerance interval K^6 and the standard deviation σ_b of the brightness. The factor of one-side tolerance interval K,on safety side, has been estimated (for numer of datapoints 10^6) as 1,700 (-).

$$\chi_{0,05} = K\cdot\left(\overline{{}^{100}\sigma_b}\right) \quad (\%) \qquad (8)$$

$$Q_{0,05} = b_{L,0,05} = \overline{{}^{100}b_{AVG}} - \chi_{0,05} \quad (\%) \qquad (9)$$

The lower tolerance interval or 5 % fractile represents the percentage of the invert brightness, in comparison to which 95 % of the pixels show higher invert brightness.

EXPERIMENTAL STUDY

This method was developed and used for assessment of uniformity of parafin emulsion application. The outcome is the average relative area with enlarged uncertainty (k=2) which is absolutely cured by applied parafin membrane. It can be identified with the average brightness ${}^{100}b_{AVG}$ (%).

There was a goal to find out the most appropriate method of application of the parafin membrane onto concrete surface to make as most uniform memrane as possible. For application, there was used a mechanical sprayer. Varying parameters of the sprayer and spraying affected overall uniformity of the application.

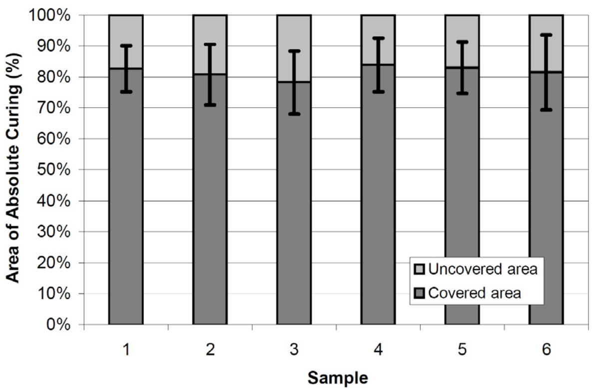

Fig.6. Relative area of absolutely cured concrete

The most appropriate parameters of application showed the uniformity around 80 %. In other words, around 80 % (with standard deviation cca 10 %) of the area was cured absolutely (fig. 6).

CONCLUSIONS

The technique of the digital photogrametry was developed and succesfully used within design of application of the parafin membrane onto concrete samples for the tests of curing efficiency when exposed to harsh weather conditions.

The method needs further precising of technique of picture capturing (shutter speed, distance, exposure) to attain the best possible result, mostly in meaning of the dynamic rande. It is also planned to work out a database of the membrane thickness in certain age which could serve as a reference in analysis and classification of the particular spots in terms of sufficient or insufficient curing.

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