Experimentální Analýza Napětí
2005

SOME ASPECTS OF IMAGE-ANALYSIS-BASED MEASUREMENT OF LATERAL DEFORMATION OF HARDENING CONCRETE

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***Abstract**: The lateral deformation of solidifying and further hardening concrete needs to be measured with a contact-free method due to the soft consistency of solidifying and hardening concrete. Some results have been already obtained with an image-analysis-based measuring method, however its use is limited, again, due to the consistency of solidifying and hardening concrete as it contains free water, which is squeezed out of the specimen and thus changes conditions for the measurement. This paper discusses the nature of this issue and possible measures to reduce its effect on the quality of measurement.*

Keywords

hardening concrete, image analysis, lateral deformation.

1. Introduction

The competition in the building industry always asks for pushing the technological limits farther so that the company can succeed in the bidding. The least expensive and earliest delivered project wins. For concrete structures it means slender structural members and minimizing the technological pause provided for concrete to harden sufficiently before the load is applied. Safe early loading requires an analysis of mechanical behavior of hardening concrete, which requires some information on the material parameters. Some material parameters of hardening concrete can be obtained with the standard testing methods developed for already hardened concrete. Some material parameters require other techniques, such as techniques based on image analysis.

The soft consistency of not yet hardened concrete prohibits the application of commonly used devices for measuring the lateral deformation, which consists in fixing a ring equipped with a strain gauge to the surface of a cylindrical specimen. An alternate method of measuring utilizes laser sensors, which are rather expensive, moreover this method brings along other drawbacks. The capturing of an image of a tested specimen and the processing of the image proved inexpensive and fairly accurate in the testing of hardening concrete specimens. Some data on the mechanical parameters, such as the Poisson's ratio in [3], were obtained with this method and thus allowed the necessary structural analyses for acceleration of construction process, [2]. However, this image-analysis-based method has some limitations. The problem stems from the consistency of hardening concrete when it contains a considerable amount of free water. The free water is squeezed out of the specimen during loading, which deters the

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edge detection due to the reflection of spotlight. This issue affects a certain part of the results for loading under normal conditions.

2. Test configuration

The basis for the experiment is represented by the standard uniaxial compression test, whose configuration is shown in Fig. 1. During the test, a cylindrical specimen (diameter = 100 mm and height = 200 mm) is subjected to loading along its longitudinal axis while the longitudinal deformation is measured by a contact standard device. In the case of hardening concrete, the lateral deformation is measured with a contact method when a device is fixed around the circumference of the specimen. However, in the case of hardening concrete, the specimen is soft and thus the contact methods cannot be used. Therefore, an image of the specimen is taken and further processed.

The CCD camera (resolution 3040 x 2016 pixels) was placed at the distance of about 40 cm from the specimen and in order to pronounce the edges of the specimen a dark curtain was placed behind the setup and the specimen is illuminated with two spotlights.

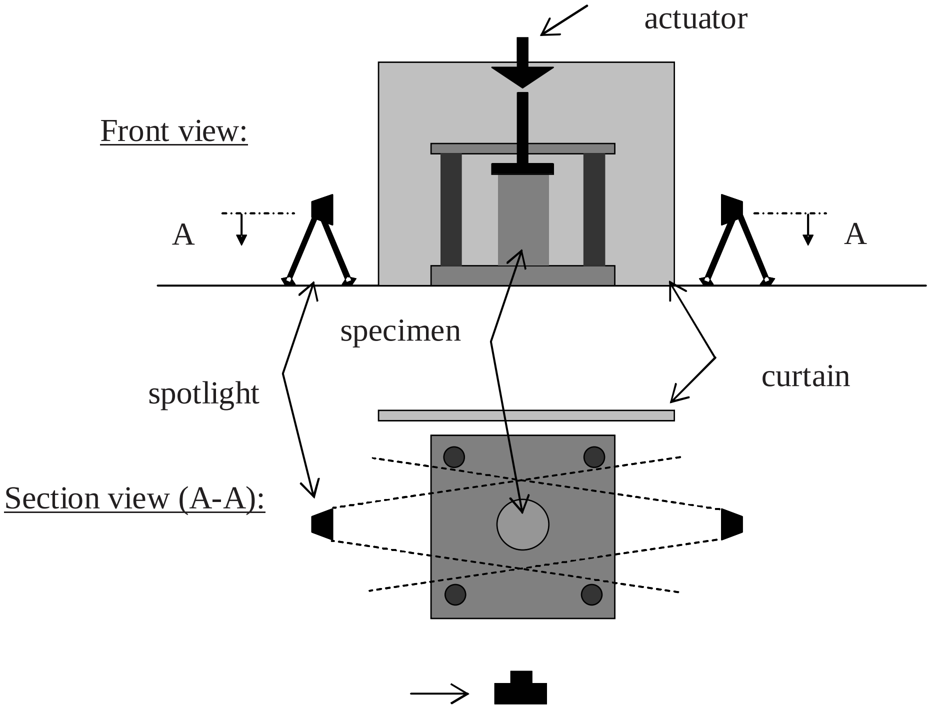


Fig. 1 Test configuration with front and section views.

3. Image processings

3.1 Methods

Each specimen was marked before the experiment so that the markers could be recognized in the images. The reason was that the camera was fixed during the test, but the longitudinal (horizontal) deformation of the specimen was quite large (in order of centimeters), and it was desired to measure the lateral deformation at the same marker.

The captured jpg images were converted into 256-gray-scale bitmaps. Then, three horizontal strips were cut out of the image at about the mid-height of the specimen according to the markers. The height of the strip had to be at least twice the size of the greatest void contained in the strip, which appears as a dark spot due to the shadow cast by the spotlights. This was done to avoid erroneous edge detection. There were three strips so that a more reliable averaged value of the lateral deformation could be obtained. The three strips, obtained for each load step, were converted into arrays of digits.

The edges were detected on the subpixel domain with help of a method seeking the center of gravity under the curve whose values were the gray-scale differences of neighboring pixels. This method was developed for this specific use and verified successfully in term of comparison with the method based on polynomial curve fitting, proposed in [1]. The flow of this method is shown in Fig. 2.

3.2 Results

Because the result of this method was the relative difference between the original specimen's width and the width at a load step, it was not necessary to convert the calculated width in pixels to the width in, e.g. millimeters. The Poisson's ratio was then obtained as the ratio of the relative lateral deformation to the relative longitudinal deformation for each load step. An illustrative example of the Poisson's ratio as a function of load level (f / f_c), where f stands for actual compressive stress and f_c stands for compressive strength at the moment of loading, is shown in Fig. 3. It can be observed in Fig. 3 that for the load levels below about 20% the readings are missing.

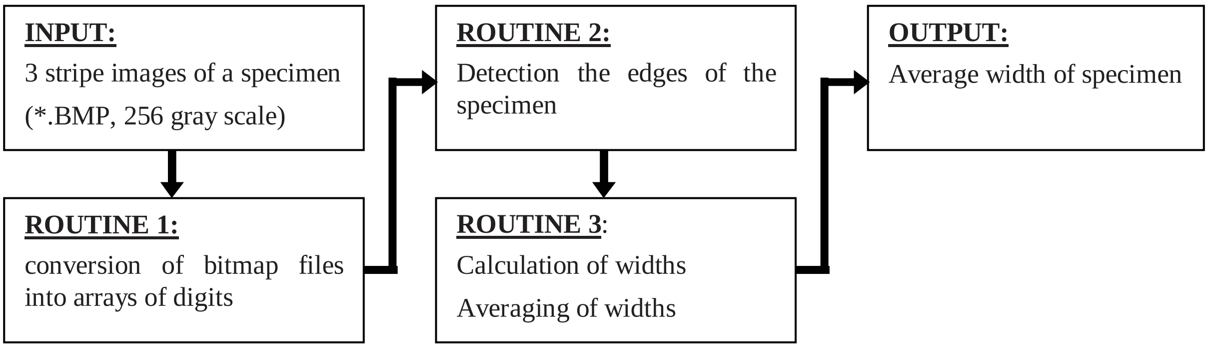


Figure 2: Flow of image processing method.

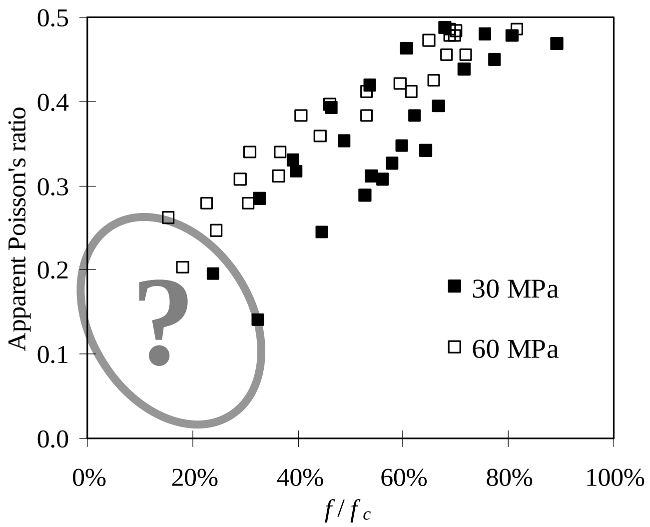


Figure 3: Illustrative example of results.

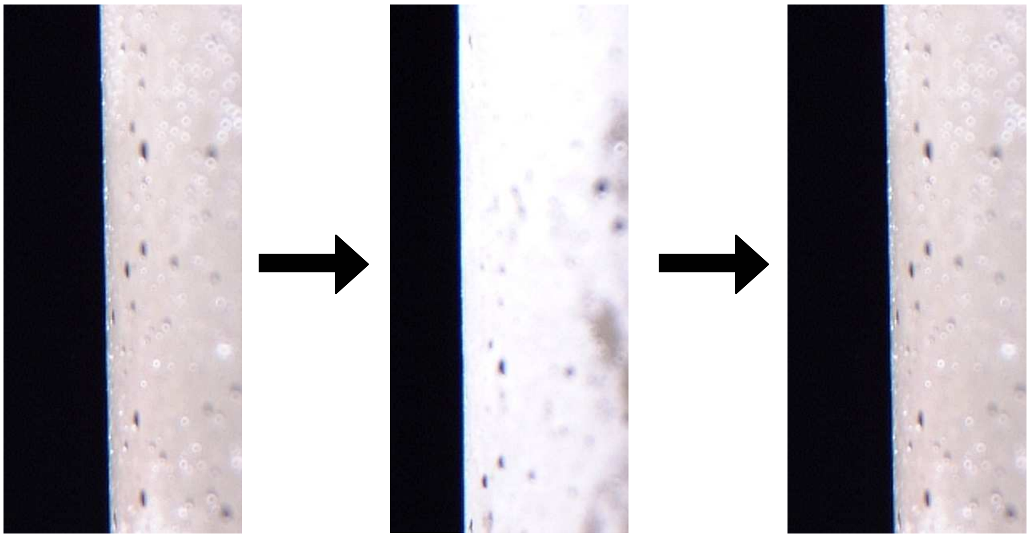
4. Issues in Image Processing Related to Hardening Concrete

4.1 Recognition of Causes of Problems

The hardening specimen (the age of concrete about 3 to 6 hours, counted from the instant when water touches cement) contains a large amount of free water (most of which later becomes chemically bound). Initially, before the loading starts, the free water is held inside of the concrete specimen. When loading is applied, the free water is squeezed out of the specimen. Then, due to the heat emitted by the spotlights the squeezed out water evaporates so that by the end of the experiment the surface of the specimen appears dry again. This sequence is shown in Fig. 4. The water reflects the light from the spotlights which changes the conditions in the edge detection, as can be seen in Fig. 5.

4.2 Possible Solution

The Fig. 3 shows that this problem affects only the region of load levels below about 20 %. In real applications, the concrete is subjected to service loads which correspond with load levels up to 30 %. In the case of hardening concrete, it is imminent that some overloading, which means load levels well above 50 %, will occur. Nevertheless, it is appropriate to explain the effect of wet and dry surface conditions on the results of measurements and assess its significance. To do so, a not loaded specimen was captured in a series of images before its surface was sprayed with water, then a series of images were taken while its surface was wet and eventually a series of images were taken in the course of time while the specimen was drying. This sequence is shown in Fig. 5. The drying was rapid due to the heat from the spotlights and its actual duration is irrelevant, but it corresponded with reaching the load level of about 20 %.



Initially dry surface

Wet surface due to squeezed out water

Finally, surface dried by spotlights

Figure 4: Change in surface condition during experiment.

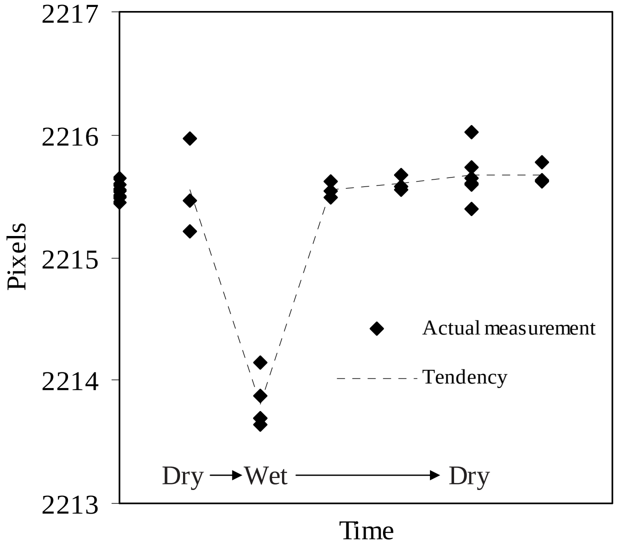


Figure 5: Change in measured width of not loaded specimen.

In order to assess the error in measurement, the not loaded specimen was first captured in a series of images whose results are shown on the vertical axis in Fig. 5. Here, it also can be seen that the method is fairly accurate as the scatter in the readings does not exceed a third of a pixel, while the width of the measured specimen was 2215.5 pixels, which means an error of 0.014 %. However, the measured differences in the width of the specimen under loading varied in order of pixels, so the actual error in measurement can be estimated as up to 10 %.

In this light, the error imposed by the change in the dry and wet surface conditions is considerable as it results in unrealistic measurements shown as the dashed line in Fig. 6. The specimen in Fig. 6 was subjected to longitudinal compression which, in reality, results in bulging of the specimen, i.e. the lateral strain increases positively. From this fact we derived the possible countermeasure.

Originally, it was tried to define some auto-correction function, but there seemed to be no way how to relate the differences in the images due to the wet and dry surfaces as the differences were measured from separate images. It was attempted to derive a function whose parameter was the sum of the gray-scale grades of pixels in the region near the edges, but there was no significant tendency recognized. Therefore, the results measured on the loaded specimens were rectified for the load levels below 20 % by the addition of the pixel difference recognized in Fig. 5 for the wet surface with respect to an appropriate ratio of the width in pixels to the metric width, which took into account the effect of the distance of the camera from the specimen. In this way, it was possible to attain more realistic results which corresponded with the results obtained for the longitudinal deformation measurement.

As a result, the value for strain, circled in Fig. 6, became positive. The almost linear increase of strain over time in this case is correct since the loading was performed by constant increase of longitudinal deformation. The circled value in Fig. 6 is not in the line with the subsequent readings which is due to the initial settlement of the specimen at the beginning of loading. The same situation was observed in the longitudinal strain.

This countermeasure is therefore effective as the realistic nature of the experimental data resumed.

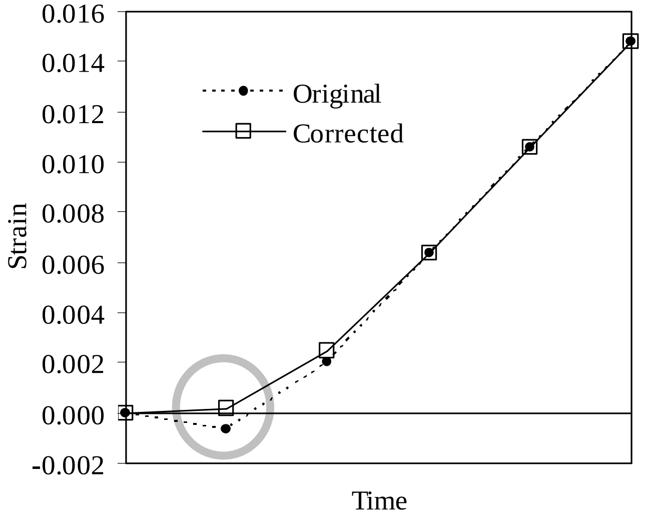


Figure 6: Rectification of lateral strain.

5. Conclusions

In this work, the cause of limitation of an image-processing-based measuring method was investigated. The free water, which was present in hardening concrete in large volume, was recognized as the cause of the discrepancies in the measurements. During loading of a specimen, the free water was squeezed out to the surface, therefore the edge detection was affected. This limitation was eliminated by the addition of the pixel difference for wet surface to the originally measured data. This simple but effective remedy was assumed as it was impossible to identify an objective auto-correction function.

Acknowledgement

This work was supported by the Grant Agency of the Czech Republic (project no. 103/05/2244), which is gratefully acknowledged.

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