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INVESTIGATION OF POISSON'S RATIO OF EARLY AGE CONCRETE

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Summary: *For an analysis of a concrete structure subjected to dynamic loading at early ages, one needs to possess reliable values of mechanical parameters, such as modulus of elasticity and Poisson's ratio. In case of solidifying and further hardening concrete, the lateral deformation 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 a large amount of free water, which is squeezed out of the specimen when loaded and thus changes conditions for the measurement. This paper discusses the nature of this issue and proposes possible measures to reduce its effect on the quality of measurement.*

1. Introduction

The competition in the concrete building industry always asks for acceleration of the construction process, which results in premature loading of yet hardening concrete. As a result, there is a demand for material models of concrete which can take into account the rapidly progressing hydration process at the very early ages. An attempt has already been made in [8] to measure the lateral deformation of hardening concrete, where an image of a hardening concrete specimen illuminated by two spotlights was captured and further processed. This technique suffered from the pronounced reflection of the spotlight caused by the free water which was squeezed out of the specimen, which ultimately affected the accuracy of the measured data for load level less than 20 %. Since the applied load at such early ages results in overloading, that means the load level well above 50 %, this issue does not constitute any significant drawback for practical application. However, to eliminate this limitation, the test configuration needed to be altered.

In this paper, the issue related to the release of free water under loading is discussed and a new measuring technique, where the test configuration is rearranged so that a shadow cast by the specimen is captured, is presented. The proposed technique, where the shadow of the illuminated specimen is measured, follows this assumption. The experimental data obtained

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by this method were used for derivation of a generally applicable relation between the Poisson's ratio and the load level, which is also presented.

2. Outline of image processing method

The recognition of the edges of the specimen was the key factor for measuring the specimen's width. Therefore, it was tried to pronounce the contrast by combination of illuminated specimen and a dark background, or a shadow cast on a whiteboard. Also, it was necessary to place some markers on the surface of the specimen as the longitudinal deformation for hardening concrete was considerable and it was desired to measure the lateral deformation at one spot during the entire experiment. The input images for the image processing were 256-gray-scale bitmaps, which were converted into an array of digits, where each digit represented a shade of grey a particular pixel. The edges were recognized as the location with the greatest difference in the shades of grey of adjacent pixels. The flow of this method is shown in Fig. 1. A detailed description of the image processing method and verification of its accuracy can be found in [2].

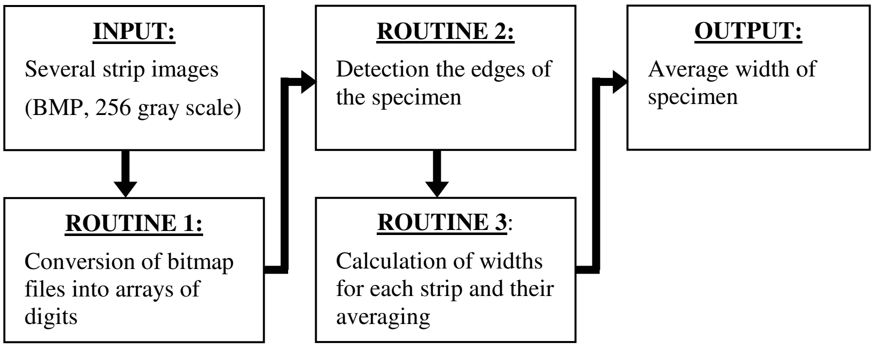

Figure 1: Flow of image processing method.

3. Original test configuration and discussion of corrective measures

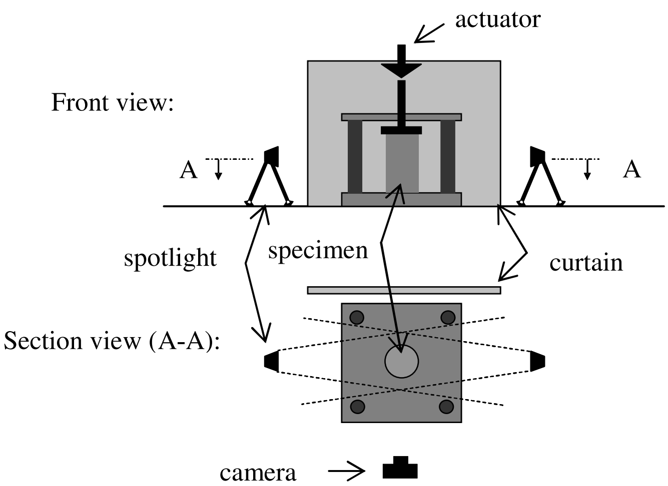

Figure 2: Original test configuration.

The basis for the experiment is constituted by the standard uniaxial compression test, whose configuration is shown in Fig. 2. 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 standard contact device. In our case, the lateral deformation is measured with help of image analysis due to the soft consistency of hardening concrete. The images are captured by a CMOS camera (resolution 3456 x 2304 pixels), which is placed at the distance of about 40 cm from the specimen and in order to pronounce the edges of the specimen a dark curtain is placed behind the set-up and the specimen is illuminated on both sides with two spotlights.

The solidifying and further hardening concrete (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 the concrete specimen. When loading is applied, the free water is squeezed out of the specimen to its surface. 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. The squeezed out water reflects the light from the spotlights which changes the conditions for the edge detection, as can be seen in Figs. 3 and 4. This problem affects only some of the data which results in obtaining inconsistent data. Therefore, its effect should be evaluated.

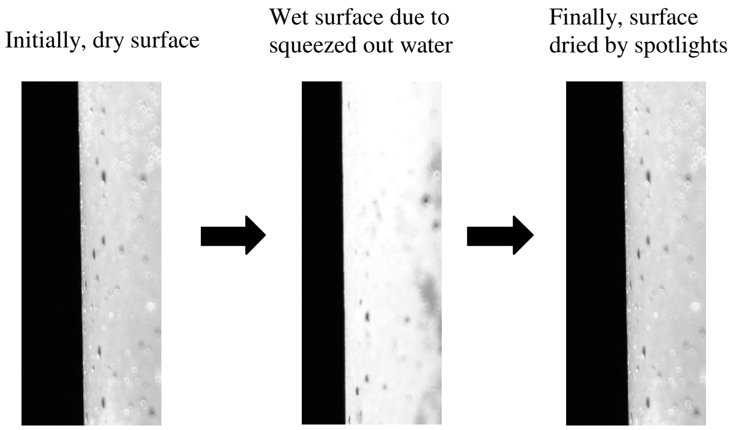

Figure 3: Change in surface condition during experiment.

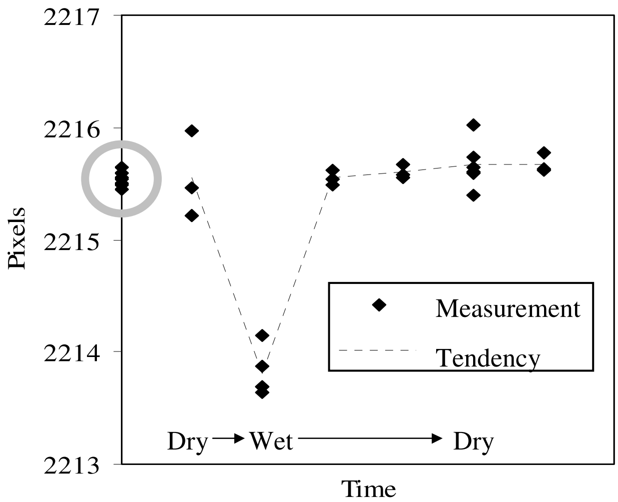

Figure 4: Effect of reflection on wet surface.

To do so, a not loaded specimen was captured in a series of images before its surface was sprayed with water. After that, 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. 4. The rate of drying depends on the amount of heat emitted by the spotlights.

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. 5. The specimen in Fig. 5 was subjected to longitudinal compression which, in reality, results in bulging of the specimen, i.e. the lateral strain increases positively. From this fact the possible corrective measure was derived.

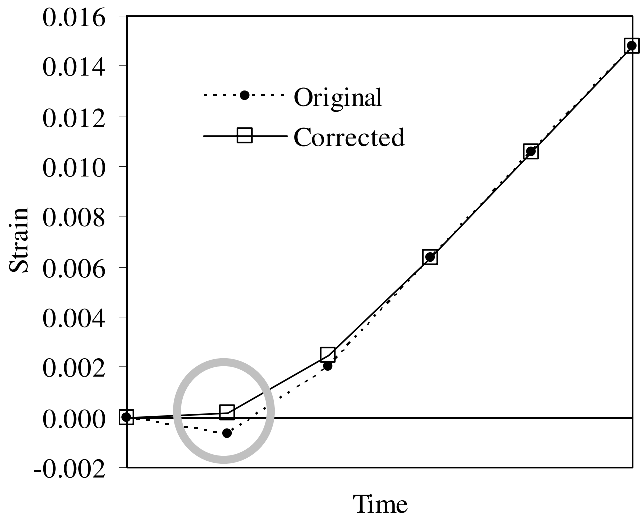

Figure 5: Rectification of lateral strain.

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 grey-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 from the longitudinal deformation measurement.

As a result, the value for strain, circled in Fig. 5, 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. 5 is not aligned with the subsequent readings, which is due to the initial settlement of the specimen at the beginning of loading. The same situation was observed for the longitudinal strain.

This corrective measure is therefore effective as the realistic nature of the experimental data resumes.

4. Rearranged test configuration and its discussion

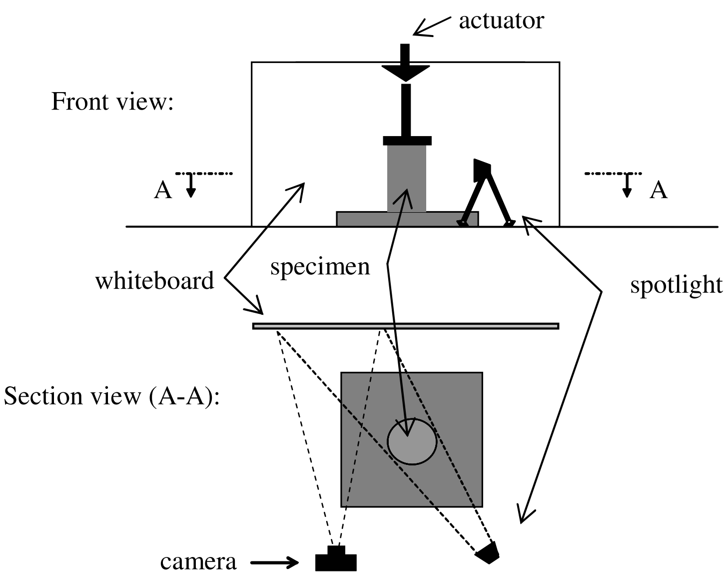

Figure 6: Rearranged test configuration.

In order to further improve accuracy of the measuring method, the test configuration was rearranged so that the shadow cast by the specimen was the subject to the measuring. As shown above, the problem was the light reflection on the wet surface which changed the condition in the edge detection, when the images captured were directly those of the specimen. In order to prevent this problem, images of the specimen's shadow were taken instead, which helped to maintain the light condition unchanged during the entire test. The test configuration is shown in Fig. 6. In this case, the contrast of the edge was obtained by installing a whiteboard with a smooth surface behind the test set-up. The camera was focused on the whiteboard and the focus was arrested. The shadow grew asymmetrically on the whiteboard with the progressing deformation, which needed to be born in mind while placing the camera before the loading started.

Because the result of this method is the relative difference between the original specimen's width and the width at a load step, it is not necessary to convert the calculated width in pixels to the width in, e.g. millimetres. The Poisson's ratio is then obtained as the ratio of the relative lateral deformation to the relative longitudinal deformation for each load step.

The width of the captured shadow of the specimen obtained by this method also contains the thickness of the thin layer of the squeezed out water. It needs to be understood that concrete is a composite material whose main components are cement, aggregate, sand and water. If the free water present in the not yet fully hydrated concrete is squeezed out of the specimen to its surface, then it should be considered as a valid part of the lateral deformation measured. If a mass of hardening concrete is loaded, the free water acts in the very much same way as the remaining components of concrete, which is, it is deformed and as such it develops pressure on the surrounding mass. The proposed measuring method with the rearranged test configuration therefore provides implicitly fairly accurate data on the lateral deformation of a specimen under uniaxial loading which also accounts for the effect of the squeezed out free water.

The main drawback of the previously proposed method was that the light reflection, causing additional smearing of the edge in the digital photograph, made the specimen appear slimmer than it actually was, as can be observed in Fig. 4. The method proposed here does not suffer from this effect any longer, moreover it even can be used to evaluate the thickness of the layer of the squeezed out water, as can be seen in Fig. 7, where the values indicated are the average values obtained from the central section of the height of a hardening concrete specimen.

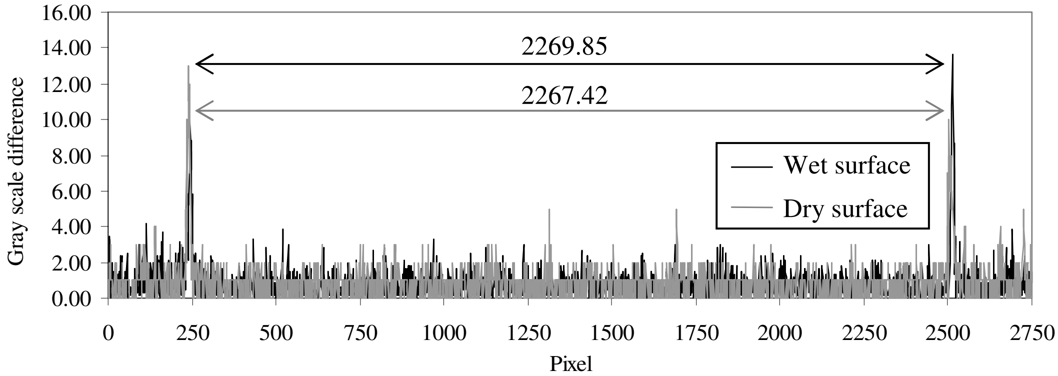

Figure 7: Grey-scale differences for dry and wet surfaces.

5. Results

The proposed method was used for measuring lateral deformation of solidifying and further hardening concrete at the ages between the 3 and 6 hours, which roughly correspond to the initial and final setting times. The concrete investigated was made of rapid hardening Portland cement with the water-cement ratio in the range from 0.37 to 0.62, which represents commonly used mix proportions. The standard cylindrical specimens were subjected to uniaxial deformation-controlled loading. The longitudinal deformation was measured by LVDT transducers while the lateral deformation was captured in images, which were subsequently processed. The loading system, the data-logger collecting the longitudinal deformation and the shutter of the high-resolution CMOS camera were controlled by a single PC. The experimental data on the Poisson's ratio as a function of the load level is shown in Fig. 8. Even though the data were obtained for hardening concrete of varying age, no tendency of evolution as an evidence of the rapidly progressing hydration was observed. However, the dependence of the Poisson's ratio on the load level is prominent. Based on the data, the following tri-linear function was derived for general application

$$\begin{aligned} \mu(S) &= 0.25 & & S \in \langle 0; 0.3) \\ \mu(S) &= 0.25 + 0.5(S - 0.3) & \quad for \quad & S \in \langle 0.3; 0.8) \\ \mu(S) &= 0.5 & & S \in \langle 0.8; 1) \end{aligned} \qquad (1)$$

with $S = f / f_c$ as the load level, where f stands for the actual compressive stress and f_c stands for the compressive strength at the moment of loading.

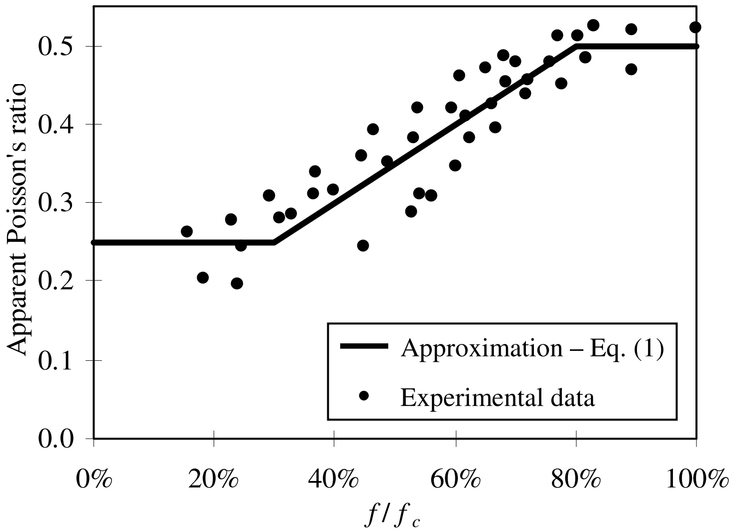

Figure 8: Poisson’s ratio as function of load level.

6. Conclusions and discussion

This paper recognized and discussed the issue related to the free water which is squeezed out of the hardening concrete specimen during loading. The free water present in hardening concrete in large volume was recognized as the cause of the discrepancies in the measurements of the previously presented method related to the changes in conditions for edge detection. Therefore, the test configuration was altered so that the shadow of the loaded specimen was captured by a CMOS camera. This method overcomes the problem of the reflection, which made the specimen appear slimmer than it actually was. Moreover, the proposed method allows measuring of the thickness of the layer of water on the surface of the specimen. The results of the experiment were used for derivation of the relation between the Poisson’s ratio and the load level valid for hardening concrete at the ages ranging from 3 to 6 hours.

7. Acknowledgement

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8. References

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