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Impact of Masonry Joints on Detection of Humidity Distribution in Aerated Concrete Masonry Constructions by Electric Impedance Spectrometry Measurements

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***Abstract*—**Aerated concrete is a load bearing construction material, which has high heat insulation parameters. Walls can be erected from aerated concrete masonry constructions and in perfect circumstances additional heat insulation is not required. The most common problem in aerated concrete heat insulation properties is the humidity distribution throughout the cross section of the masonry elements as well as proper and conducted drying process of the aerated concrete construction because only dry aerated concrete masonry constructions can reach high heat insulation parameters.

In order to monitor drying process of the masonry and detect humidity distribution throughout the cross section of aerated concrete masonry construction application of electrical impedance spectrometry is applied. Further test results and methodology of this non-destructive testing method is described in this paper.

***Keywords*—**Aerated concrete, electrical impedance spectrometry, humidity distribution, non-destructive testing.

I. Introduction

TODAY'S construction is oriented on sustainable use of construction materials and energy. Heat insulation parameter is one of the most important parameters of the construction after its load bearing capacity and stability. Aerated concrete is one of such materials, which combine high load bearing capacity when it is used in masonry constructions as masonry material [1], and high heat insulation parameters.

The most common problem in use of aerated masonry constructions is ensuring proper drying conditions for the masonry construction on construction site. This type of masonry reaches its highest performance qualities in aspect of heat insulation only when it is in air-dry state and its relative humidity rate does not exceed 10-15%. It is the reason why monitoring of the drying process is very important for aerated concrete masonry constructions. For on-site monitoring non-destructive testing methods are preferable due to easy application and possibility to perform measurements in various places of the building. The most of the non-destructive testing methods allow determining average humidity rate of the whole cross section of the construction or a part of it depending on the method and testing device used. Application electrical impedance spectrometry allows determining humidity distribution throughout the cross section of the whole construction if Z-meter device is used [2], [3]. It is important to determine humidity distribution throughout the cross section because it affects heat insulation properties of the construction [4].

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II. Methodology

For this particular research Z-meter III device has been used which works with electrical impedance spectrometry measurements.

Method of electrical impedance spectrometry (EIS) enables detection of the distribution of impedance or other electrical variables (such as resistivity, conductivity etc.) inside a monitored object, and thus the observation of its inner structure and its changes [5], [6]. This method ranks among indirect electrical methods and it is used in measuring properties of organic and inorganic substances. So far, EIS is widely used in medicine as one of the most common testing methods in diagnostics where any kind of tissues are involved. It constitutes a very sensitive tool for monitoring phenomena that take place in objects (e.g. changes occurring in earth filled dams when loaded by water, in wet masonry sediments etc.), electrokinetic phenomena at boundaries (e.g. electrode/soil grain, between soil grains) or for describing basic ideas about the structure of an inter phase boundary (e.g. electrode/water) [7].

The EIS is based on the periodic driving signal – the alternating signal. If low amplitude of the alternating signal is used, concentration changes of charge are minimal at the surface of an electrode connected with the measured surface, which is very important in systems sensitive to so called concentration polarization. The range of frequencies used for the driving signal enables the characterization of systems comprising more interconnected processes with different kinetics.

In the Laboratory of Water – Management Research of the Institute of Water Structures at the Civil Engineering Faculty of Brno University of Technology, a measuring instrument with a Z-meter III device has been developed within the solution of an international project E!4981 of programme EUREKA. This instrument is verified in laboratory experiments and measurements on objects in situ [8], [9].

III. Previous Research in Field of Non-Destructive Humidity Measurements

Many researches have been performed in order to detect non-destructive test methods for the detection of relative humidityrate in constructions (mostly in concrete). The most precise and credible test method is destructive – gravimetric method.

Gravimetric method consist on determining water content through weighting samples upon oven drying, encompassing absorbed and chemically bound water. There are automatic moisture analyzers that utilize infrared lamps as a heat resource as well. This technique measures the weight loss of hardened concrete slices or specific portions, by comparing to the original weight of the sample, and then the lost of water can be determined. The results may be expressed by weight as the difference of the mass of water present to the dry weight of the concrete sample or by volume as difference of the volume of water to the total volume of the concrete sample [10]. This method is considered to be the most direct and reliable procedure despite the large number of specimens it is required, since different samples should be used for each measure, and only the average water content of each portion or slice should be obtained. It is also one of the few methods that can be employed at high moisture contents [11].

H. Akita et al. 1996 [12], proposed the analysis of prismatic concrete specimens in order to quantify the moisture transfer experimentally and numerically (Fig. 1). Variations in water content were measured at European Union Governo da República Portuguesa different depths by splitting the specimens and comparing the mass of each peace before and after oven drying at 105°C. [13].

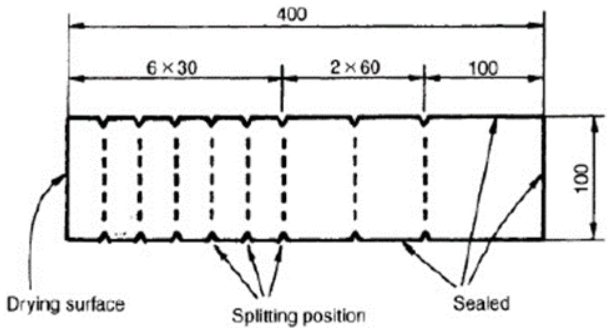

Fig. 1 Dimension (mm) of specimens subjected to one-face drying [12], [13]

Such approach can provide credible results about humidity distribution throughout the cross section of the construction but it is long and laborious process, which is hard to repeat in many places on construction site. However, this method can be used for controlling of the non-destructive test results.

The gamma densitometry is a nondestructive testing method commonly used to control the density of civil engineering materials [13], [14].

The principle of this method is based on a beam of gamma rays emitted by radioactive source and passing through the concrete (Fig. 2). The relative intensity of the transmitted particles is related to the mass of the traversed material mc, the mass variation of the traversed points can thus be measured. Since chemical evolutions do not lead to significant losses of mass, the mass variation in these beams stem solely from water evaporation; and can be interpreted as the profile of water content variations [13], [15].

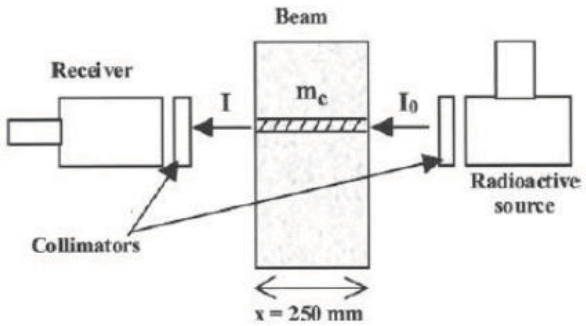

Fig. 2 Principle of the gamma densitometry technique [13], [15]

The gamma densitometry is based on absorption of the gamma ray emitted by a radioactive source of Cesium Cs137 [14]. The relation between intensity I of the flow of transmitted particles and traversed mass mc is as follows is based on the Lambert´s Law [15].

The mass variation of the volume intercepted by the gamma ray can be measured at different depths, so water content variation along the height of the concrete beam´s cross section can be monitored. The calculation method assumes that at each measurement the flow intercepts the same volume of material [13], [15].

This method allows determining humidity distribution throughout the height of the cross section by non-destructible method, but it can hardly be used in on-site conditions and is mostly laboratorial test method. Other restriction on this method is described in [13].

High quality relative humidity sensors are usually made of hair from horses or humans. The movement of the hair is converted into an electrical signal by a strain gauge. Similar sensors are made of a strip cellulose butyrate, a water absorbent polymer that likewise stretches and shrinks according to relative humidity.

There are two main types of relative humidity sensors, capacitive and resistive sensors. The capacitive sensor consists of a thin layer of water absorbent polymeric or inorganic material that is coated onto a conductive base. This layer is then covered with porous conductive layer material. With the increase of the relative humidity, the water content of the polymer increases too. Water has a high dielectric constant, which means that the combination of two electrodes with the water between can store a relatively high electric charge. This electrical capacity is measured by applying rapidly reversing (AC) voltage across the electrodes and measuring the current that passes. The polymer or inorganic material is usually aluminum oxide and just plays an indirect part of the measurement. The change of capacitance of these capacitive sensors is, however, small when even compared with the capacitance of few meters of cable. This means that the electronic process of data acquisition has to be completed close to the sensor. If one data logger is connected to several relative humidity sensors, each sensor will need its own power supply and relatively bulky electronics [13], [16].

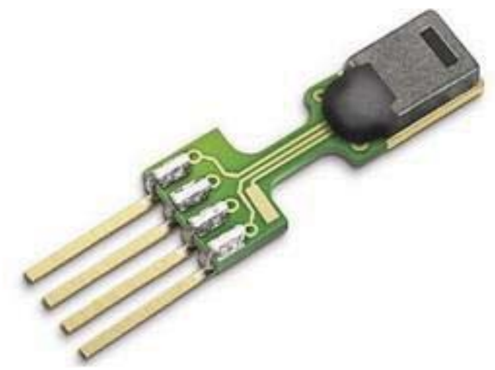

Fig. 3 (a) Capacitive sensor [13]

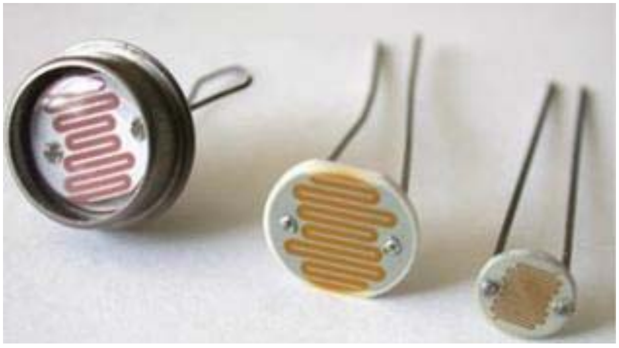

Fig. 3 (b) Resistivity Sensor [13]

Using capacitive sensors, [17] measured the relative humidity, at an age of 1 day, in concrete specimens with water/cement ratio 0.44 after two sides of the specimens have been exposed to 50% RH ambient conditions. Although capacitive sensors can have reduced accuracy at relative humidity values exceeding 90%, they typically provide better linearity than resistive sensors. However, capacitive sensors can take several hours to reach equilibrium and provide valid readings [18]. They cannot also be directly exposed to fresh concrete. To solve this problem in the experiment, the sensors are mounted in plastic tubes with Gore-tex® caps and then embedded in fresh concrete. This material, protect the sensor from liquid water but allows vapor transmission. The vapor pressure within the airspace around the sensor and in the concrete pores will always be equal. This allowed the sensor to be permanently embedded in the concrete reaching its equilibrium and obtaining valid readings [13], [17].

This method in its base is similar to the EIS method with the exception that the sensors should be left inside the structure, so it requires large amount on sensors which have to be embedded in constructions during the construction phase and left there for further measurements. EIS method with Z-meter allows using only one probe pair for all measurements because probes can be withdrawn from the construction after the measurement.

Experiments with EIS method for the detection of humidity distribution throughout cross section of aerated concrete constructions have been performed in Riga Technical university bt Z-meter III device and methodology for measurement process is being developed [9], [19], [20].

EIS method can be applied for nondestructive detection humidity level throughout aerated concrete constructions. It is easily applicable for testing of relative changes of humidity level in construction. In such cases no prior calibration of the Z-meter III device is necessary. As there are several types of probes which can be used as sensors for fully nondestructive testing and probes which require prior drilling of holes in construction in order to make accurate measurements the method gives opportunity to apply it for different constructions and situations. The most efficient and convenient type of probes is type 1 (probes, which are inserted in the construction, Fig. 4).

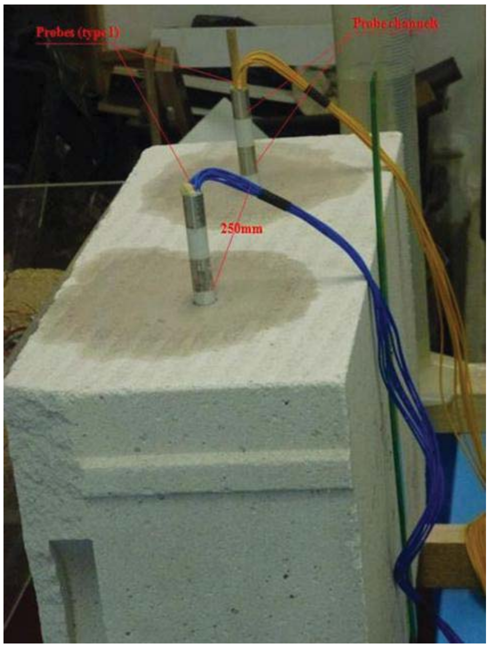

Fig. 4 Type 1 probes inserted in aerated concrete block

With such probes it is not necessary to access construction from both sides which are rather difficult for in situ testing.

It is also possible to determine the distribution of absolute humidity rate within construction with the EIS method. In such case calibration work in laboratory must be done before the in situ testing in order to determine the correlation of the electric impedance value and absolute humidity rate of the construction. The advantage of EIS method against commonly used method of determination the material humidity rate by weight differences in dry and saturated conditions is that EIS can show the distribution of the humidity throughout the section of the construction. Other commonly used methods do not allow obtaining such data. The method of determination of absolute humidity rate by EIS in aerated concrete constructions is subject of further research.

IV. Experiments

The particular experiment was performed on aerated concrete block masonry wall segment in laboratory of Riga Technical University. AEROC aerated concrete blocks with dimensions 300x200x600mm (width x height x length) (Fig. 5) were used [1].

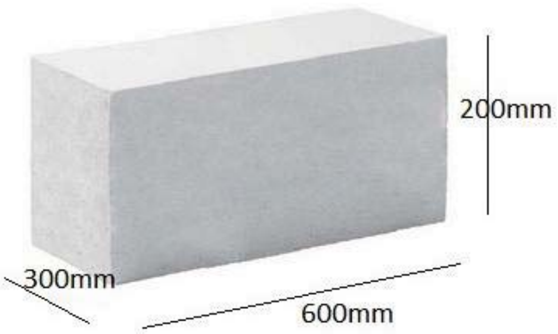

Fig. 5 AEROC aerated concrete block

The wall segment consisted of 6 blocks as in Fig. 5 and 23 (twenty three) measurement points were made in this segment as in Fig. 6.

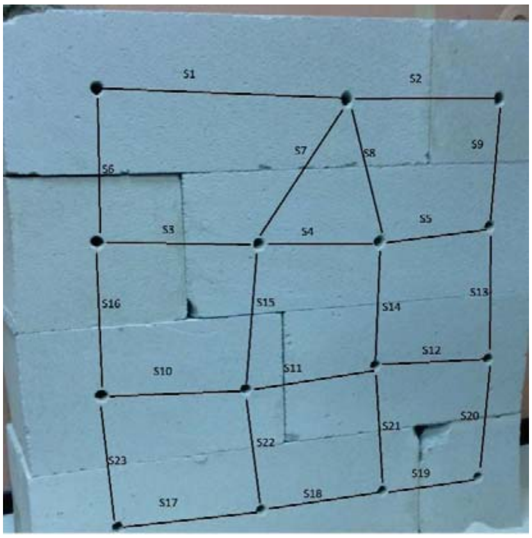

Fig. 6 Aerated concrete wall segment and measurement points

The aim of this experiment is to determine the impact of the masonry joints on detection of the humidity distribution by EIS method. So for the reasons of comparison series of s1-s2; s3-s4; s10-s11-s12 and s18-s19 measurement point will be taken into consideration.

EIS measurements were performed during drying process of newly built aerated concrete masonry wall segment where parallel measurements were made within one block and within two blocks where a masonry joint is included in the measuring distance. In such way there were obtained 5 pairs of comparable results where the impact of masonry joints can be observed.

V. Results

Drying process of the aerated concrete block without masonry joint in measurement distance in point s1 (Fig. 7) and point s2 with masonry joint (Fig. 8) show that the character of measurements is similar but the absolute measurement values are significantly different. That means that masonry joints have significant impact on EIS measurement results and results, which are obtained in wall segments without joints, are not directly comparable to results, which are obtained in wall segments with masonry joints.

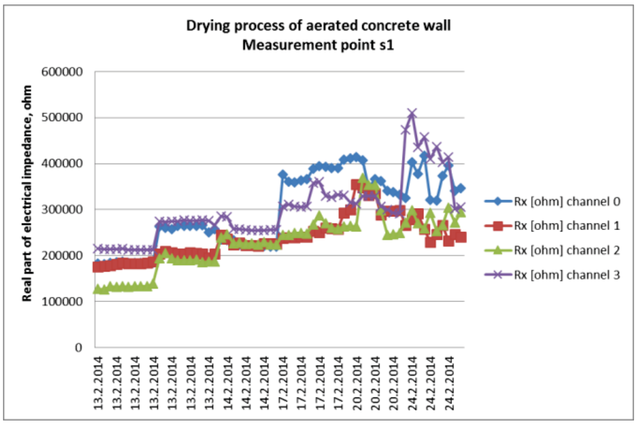

Fig. 7 Drying process of the aerated concrete wall fragment without masonry joints

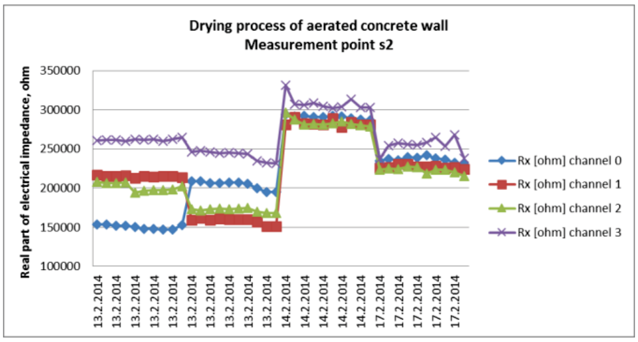

Fig. 8 Drying process of the aerated concrete wall fragment with joint between measurement points

The difference in second series of the measurements between Figs. 7 and 8 are proving the theory about joint impact on measurement results because the first series of the measurements were performed prior filling the joints with glue mortar. It affected the results impressively.

The absolute values of EIS measurements in points s1 and s2 for the same measurement series change almost twice in their values so it is clear that the masonry joints have their effect on the final measurement results.

Therefore, in five pairs of the comparable results, several correlation tables were created and correlation formulas between measurement results with and without masonry joints were found.

As it concerns measurement point pair s1-s2 the results were following (Fig. 9).

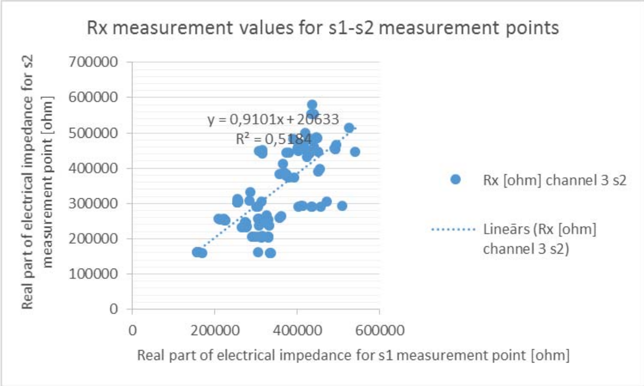

Fig. 9 EIS measurement results with masonry joint impact s1-s2

As of Fig. 9 the impact of masonry joint can be expressed by (1):

$$y = 0{,}9101x + 20633\ [ohm] \tag{1}$$

where (1)-(4) x is EIS measurement value in masonry segment without joints and y is EIS measurement value in masonry segment with joints.

The same results were obtained for measurement points s3-s4, s10-s11, s11-s12 and s18-s19 (Figs. 10-13).

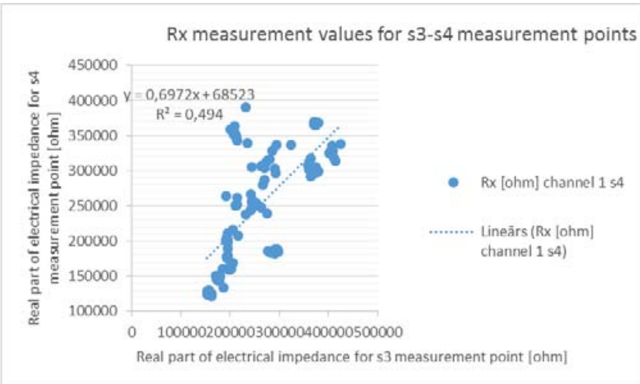

Fig. 10 EIS measurement results with masonry joint impact s3-s4

In this case (Fig. 10) the impact of joint is expressed with (2):

$$y = 0{,}6972x + 68523\ \ ohm \tag{2}$$

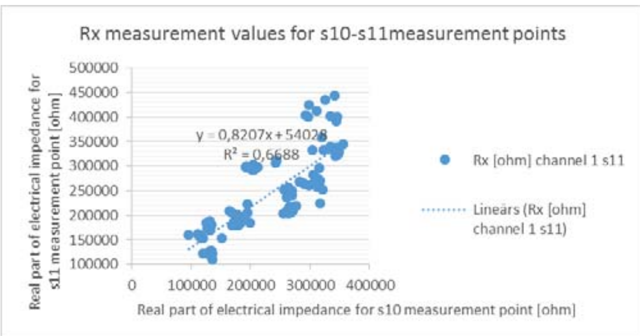

Fig. 11 EIS measurement results with masonry joint impact s10-s11

In this case (Fig. 11) the impact of joint is expressed with (3):

$$y=0{,}8207x+54026\ [ohm] \tag{3}$$

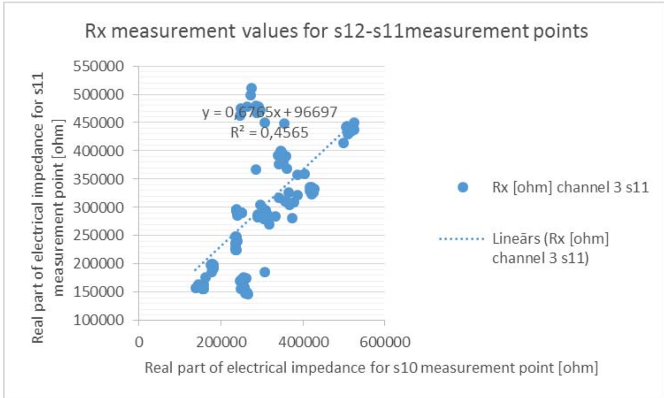

Fig. 12 EIS measurement results with masonry joint impact s12-s11

In this case (Fig. 12) the impact of joint is expressed with (4):

$$y=0{,}6765x+96697\ [ohm] \tag{4}$$

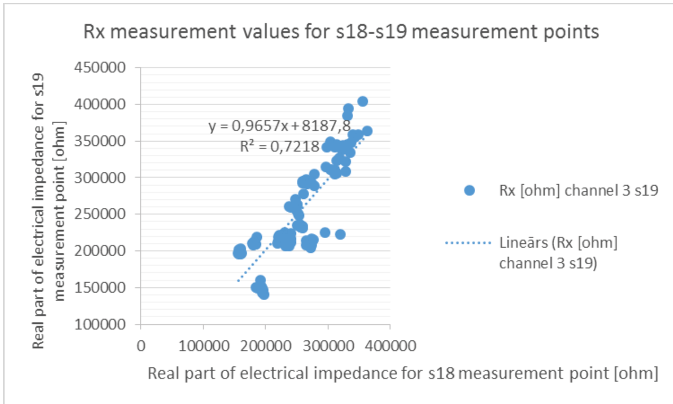

Fig. 13 EIS measurement results with masonry joint impact s18-s19

In this case (Fig. 13) the impact of joint is expressed with (5):

$$y=0{,}9657x+8187{,}8\ [ohm] \tag{5}$$

From (1)-(5) it is obvious that there is a linear correlation between measurements which are made in sectors without joints and sectors including masonry joints which goes to basic equation:

$$y = ax + C \tag{6}$$

The a quotient is in range of 0,67 to 0,96 that mean the impact factor of joint is in the same range accordingly to base measurement value in section without joints. However, the C constant is different every time and it is difficult to conclude what it depends on. The value of C constant has to be a subject of further research.

VI. Conclusion

For the present EIS is the only non-destructive testing method, which is tested on aerated concrete masonry constructions and provide credible test results in humidity distribution measurement tests. The methodology is fully applicable in measurements where no masonry joints are involved. However, the impact of masonry joints to the test results is not fully explored. It is determined that the impact of joints can be described with a linear equation where a quotient is in range of 0,67 to 0,96 but the value of C constant is a subject of further research.

Acknowledgment

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