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EVALUATION OF APPLIED REMEDIATION WORKS ON HISTORICAL MASONRY WALL EXPOSED TO LONG-TERM DETERIORATION

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The exposure of massive historical masonry walls to varying climatic conditions represents a crucial factor for long-term damage related to moisture and soluble salts increase. Moisture movement in the porous structure of massive historical masonry wall driven by capillary forces is usually connected with transport of salt solutions, which can be responsible for a severe damage. Because of missing damp-proof insulation layers, the moisture ingress carrying soluble salt from the ground especially during winter periods is not prevented from. This study is aimed on the evaluation of the effect of commonly used restoration works on the conservation of an exposed building. The influence of applied precautions was continuously monitored by time-domain reflectometry probes in various depths and heights of the studied masonry wall located in the basement of a residential house in Prague, Czech Republic. Based on the obtained results, taking into account also the influence of indoor and outdoor temperature and relative humidity variations monitored by combined temperature/relative humidity sensors, the wall drying process and the success of applied methods is analyzed.

Keywords: Brick, Time domain reflectometry, Moisture content, Drying experiment, In-situ analysis.

1 INTRODUCTION

The exposure of a building to varying climatic conditions is accompanied with the potential risk related to the durability of used building materials. In particular, increased moisture content in the old masonry structures represents a serious risk connected with disintegration of inorganic plasters, biological and chemical corrosion, frost damage, salt efflorescence and devaluation of hygienic conditions of interior climate. The rising damp and problems with the missing hydroinsulation layers are important problems for old building structures suffering from high moisture content. Related problems negatively affecting their service life and cost present the worse thermal resistance due to the water presence (Franzoni 2014). Various forces drive the water ingress in the porous structure of building materials. The water capillary action can be considered as a major phenomenon responsible for rising damp in masonry structures, when the maximal rise height is related to characteristics of the porous space of the examined material. The usual rise heights reach a range about of 0.5 – 1.5 m but some observations revealed the maximal height about four or even 5.4 m in dependence on wall thickness (Sandrolini and Franzoni 2007).

A variety of methods and repair systems employed for preserving service life, mitigation of negative influence of water presence related problems and removal of moisture from masonries were described and discussed in literature (Pavlíková *et al.* 2011). Among others, precaution consisting of creation of arches in the wall, wall cutting, and application of damp-proofing barriers are the mostly used methods for reduction of wall sorptivity (Netinger *et al.* 2009). In some cases, when the high content of moisture is recently present in the masonry wall, systems improving evaporation are used to remove unnecessary water from the material. The Knapen tubes, wall base ventilation, restoration plasters and additional heating of wall surface represent often-applied methods for drying of masonry structures (Tamas and Tuns 2008).

The important issue for investigation of the capillary suction is precise measurement of material moisture and evaluation of the efficiency of adopted precautions. Several traditional destructive techniques based on gravimetric principle are often not suitable for long-term monitoring, because of low sensitivity and inconsistency (Roels *et al.* 2004). Many non-destructive methods were employed for both laboratory and in-situ monitoring of moisture content lately. The Time Domain Reflectometry (TDR) represents a relatively new approach for evaluation of moisture content in building materials. One of the main advantages of this method is possible utilization for continuous measurement with number of probes placed in various depths or heights. The specific calibration for each probe allows sensible temperature compensation according to actual temperature due to well-known dependence on relative permittivity and temperature.

Within this paper, the evaluation of performed remediation works aimed at mitigation of leakage of ground and sewage water from the subsoil is presented. Selected precautions consist of application of restoration plaster, waterproof layer in the underground part of building and creation of sub-soil drains.

2 STUDIED BUILDING, MATERIALS AND METHODS

2.1 Description of Studied Object

The object of interest is a six-story brick apartment building oriented with its main facade to the west (Figure 1). The building is on the west adjacent to a grassy area and gutter pavement. From the north, a public sidewalk runs along the building at a level between the ground and the first floor. The court is adjacent to the east side of the building at a level of about 1.4 meters above the first floor. From the western and southern sides, it neighbors with surrounding houses with the first floor approximately at the same level as the researched area.

The building walls with a thickness about of 0.9 m are composed of historical brick with the following parameters: bulk density – 1 691 kg/m^3, matrix density - 2 659 kg/m^3 and total open porosity – 36.4%.

In the years 2013 to 2014 remediation works were carried out on the building, to prevent groundwater leakage to the basement and building substructure. The main aim of these works lies in the reduction of moisture content in the walls of the first floor and the preparation of appropriate building and construction conditions for the considered future thermal insulation of the building. Remediation works were based on the initial research focused on the moisture content increase in the building walls. On the basis of the performed investigation, following possible sources of moisture can be highlighted: impaired downpipes pipes or sewage water pipes, a leakage of rainwater to the building substructures and high groundwater level associated with construction of the underground parking in the neighborhood made in recent years, coupled with inadequate insulation of underground part of the house.

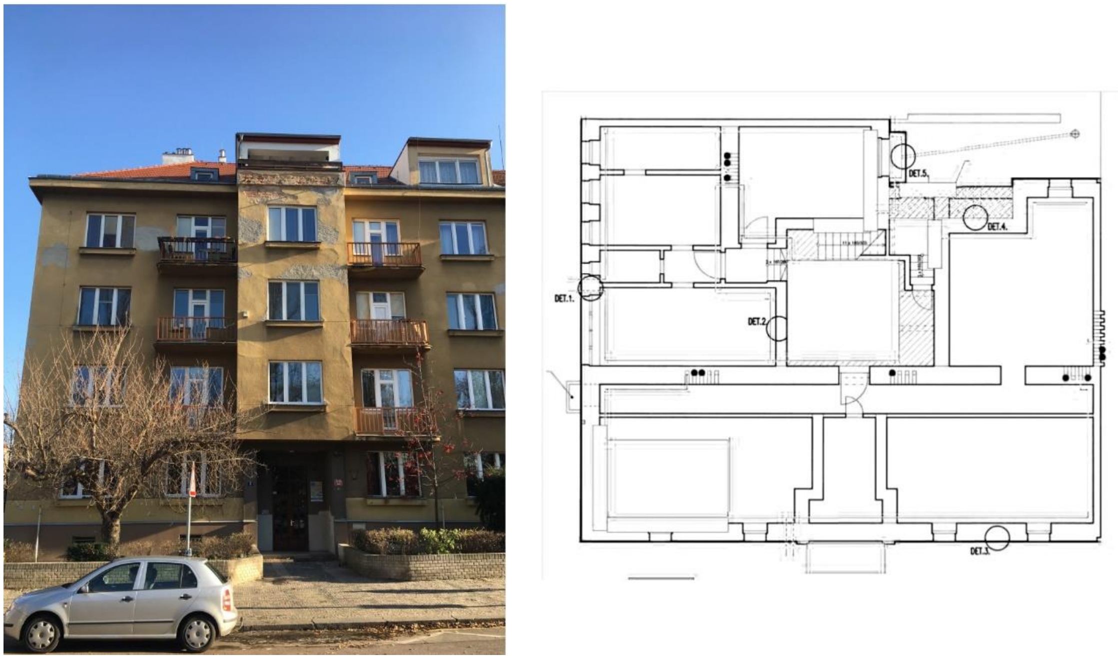

Figure 1. Photo of studied object and ground plan of basement.

During the remediation, following works were conducted: the insulation of the underground part of the building up to the depth of about one meter, restoration of reflective line along the house, terrain adjustments leading to rain water removal from the building, repair of sewage water pipelines and rain downpipes, exchange of the plasters in the basement and their replacement by the restoration plaster Baumit Sanova.

2.2 Experimental Methods

The initial moisture content was determined by the gravimetric method. For the purpose of gravimetric analysis, the dust samples were gathered from different depths and heights in accordance to the placement of TDR probes. The dust samples were collected by using drill with a diameter of 16 mm and subsequently inserted into plastic containers. Their weights were obtained and samples were dried at the temperature of 105 °C to steady state mass.

The principle of TDR method is based on launching electromagnetic waves and measuring the time interval between launching the waves and detecting the reflections from the end of the transmission line. The device used for observation of the electromagnetic pulse echo in the time domain is an important element in any TDR equipment. TDR/MUX/mts cable tester (Easy Test) connected with PC for data logging and equipped by eight miniprobes LP/mt was used in the measurements in this paper. Sensors consisted of two 53 mm long parallel stainless steel rods, 0.8 mm in diameter and separated by five mm. According to the information provided by producer, measuring range of the relative permittivity is from two to 90, the absolute uncertainty is two for $\varepsilon \geq 6$ and one for $2 \leq \varepsilon \leq 6$. The resolution of the relative permittivity measurement is 0.1 (Pavlík *et al.* 2012). The TDR probe placement is given in Figure 2.

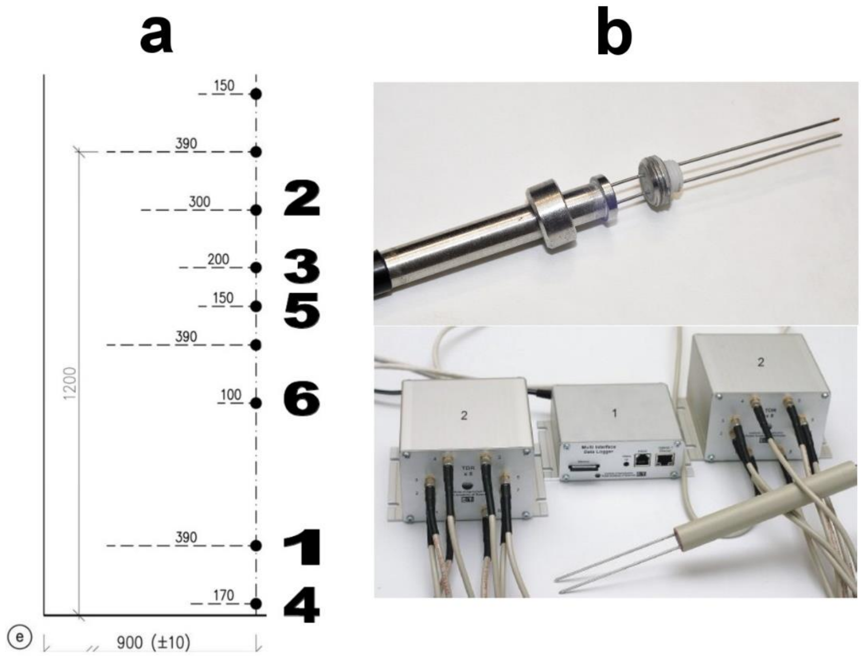

Figure 2. (a) Probes placement in the wall cross-section; (b) photo of TDR probe.

3 RESULTS AND DISCUSSION

The effectiveness of remediation works is related to the ambient and outdoor weather conditions, as it was described by Hall *et al.* (Hall *et al.* 2011). In light of this view, the outside and inside temperature and variations of relative humidity were continuously monitored. The logged data in Table 1 show monthly average temperatures and relative humidity levels, for a more detailed insight.

Table 1. Outdoor and indoor conditions.

Month	Exterior conditions		Interior conditions	
	Temperature [°C]	Relative humidity [%]	Temperature [°C]	Relative humidity [%]
January	1.3	79.2	6.7	68.7
February	1.4	82.9	6.3	67.7
March	5.6	733	7.6	69.3
April	10.5	57.8	8.3	69.5
May	15.2	58.8	11.7	75
June	20	68.9	14.1	77.1
July	23.7	69.3	16.4	80.3
August	24	64.9	18.3	81.5
September	16.2	73.5	16.2	79.8
October	9.8	76.7	11.8	76.3

During the winter, the indoor average temperature in the building basement did not drop below 11.2 °C, while the maximal temperature was observed during June. The indoor relative humidity varied around 70 % throughout the year with only small deflections, which significantly affected the drying process of the walls by decelerating moisture evaporation. The excessive indoor relative humidity can be explained by the evaporation of water from the drying walls. This effect can be mitigated by regular ventilation, which can accelerate the evaporation of the moisture and reduce the possibility of mold growth.

Moisture content was firstly estimated by the gravimetric method for initial calibration of TDR probes. Based on the initial data, TDR was employed for continuous and long-term moisture monitoring in the studied wall in the time period of January 2015 to October 2015. The record of the TDR measurement in dependence on the probe depth is plotted in Figure 3.

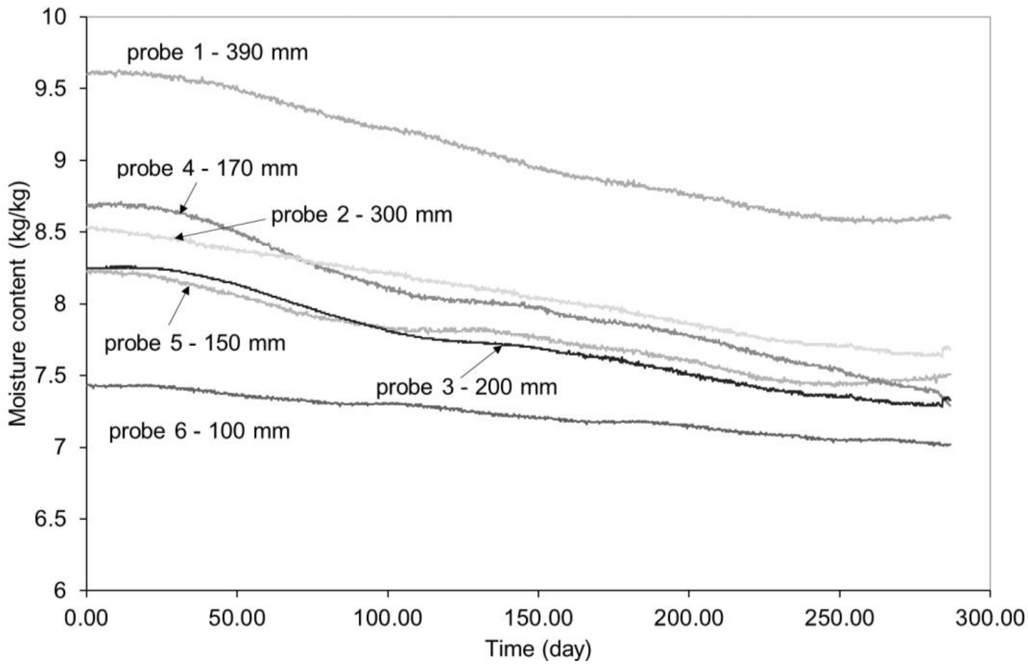

Figure 3. Record of TDR measurement in various depths.

According to the classification of ČSN P 730510, all collected samples exhibited high initial moisture content. The moisture development in time was similar in the cross-section of the wall where moisture content values exceeded 8.2 wt%. However, in the depth of 100 mm the moisture content reached only approx. 7.5 wt% due to the evaporation of water to the interior environment.

The data obtained by continuous TDR measurement carried out during the reported period revealed a decrease in moisture content for all probes. Whereas an average decrease of 1.7 wt% was noted, the lowest decrease of 0.7 wt% was obtained for the probe in 100 mm depth. Apparently, the moisture was removed faster into the exterior environment, in the summer period in particular. The high relative humidity inside caused a lower evaporation rate.

4 CONCLUSIONS

The presented in-situ analysis provided substantial information about the efficiency of performed reconstruction work on the brick building suffering from excessive moisture content.

Remediation solutions consisted of insulation of the underground part of the building, restoration of reflective line along the house, terrain adjustments, repair of sewage water pipelines and rain downpipes. The exchange the plasters in the basement and their replacement by the restoration plaster was done in order to improve building and construction conditions for the considered future thermal insulation. The impact of the performed works was monitored by a continuous TDR measurement, which was able to detect even relatively small changes in the moisture content in dependence on the depth of the probes placement in the wall cross-section. The application of TDR probes calibrated by the initial moisture content obtained from the gravimetric method was proved as suitable for non-destructive long-term moisture monitoring. Although the decrease of moisture content was noted all over the analyzed wall cross-section within the reported time period from January 2015 to October 2015, the intensity of the drying process was affected by the ambient climatic conditions, in particular the high level of relative humidity inside. The evaporation of moisture is known to depend on many factors, the air circulation being one of the most important. From this point of view the interior space could not be considered as an ideal environment for moisture evaporation. Therefore, the application of a ventilation system is recommended to improve the efficiency of the performed remediation works.

Acknowledgments

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